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PACIFIC SLOPE BRANCH NOT TO MEET IN 1945

By unanimous agreement the Pacific Slope Branch of the American Association of Economic Entomologists has decided not to hold the usual meeting in 1945. This action was taken in an effort to cooperate with the Office of Defense Transportation in view of the transportation situation existing on the West Coast.

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DDT to Control the Little Fire Ant

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The little fire ant, *Wasmannia auropunctata* (Roger), is an important pest to citrus-grove workers in some sections along the east coast of Florida. The ant nests in the soil or under debris such as fallen branches and fallen leaves, and visits the citrus trees to obtain honeydew secreted by whiteflies, mealybugs, aphids, and other insects found on citrus. In some groves great numbers of these ants are present, and it is impossible for workers to pick fruit, prune, or spray without becoming covered with them and being stung many times. A single sting causes considerable irritation to most individuals. The characteristic symptoms are a welt surrounded by a red, splotchy area, and a severe burning and intense itching sensation which may prevail for 30 minutes or more. These symptoms disappear after a time, but itching of the affected part may recur at intervals for several days. Citrus-grove workers, and especially fruit-picking crews, have refused at times to work in trees infested with this ant. In other instances pickers have left the trees partially picked, or have demanded a premium wage.

Results of experimental work conducted during the past few years on the control of this pest, in which poisoned baits and other insecticidal treatments were tested, have not been satisfactory. Sprays containing oil, pyrethrum, derris, or dinitro-o-cyclohexylphenyl will destroy many ants, but heavy reinfestation occurs a week or two following treatment. DDT has been found to be much more toxic, and to provide more permanent control than any other material tested. Although many factors affecting the use of DDT for control of this ant remain to be studied, some of the early results are so outstanding that they warrant mention at this time.

Two series of experiments are being carried on in St. Lucie County, Fla., in two grapefruit groves which are heavily infested with the little fire ant. The first series consists of two sprays and three banding treatments, and the second of five sprays and a dust treatment, all containing DDT. The sprays were prepared by dissolving 8 ounces or 1 pound of DDT in 1 gallon of No. 2 fuel oil, adding 38 ml. of glyceryl oleate to make a stock emulsion, and then diluting with water to make 100 gallons. The sprays were applied with a power sprayer, with care to cover thoroughly the tree trunks and heavy limbs.

The banding materials consisted of 10, 5, and 1 per cent of DDT in pyrophyllite mixed with enough water to make a paste suitable for application with a paint brush. They were applied in bands 8 to 10 inches wide around the tree trunks below the lowest branches.

The experimental design was that of randomized blocks; each block was replicated 5 times and a single tree in each block received each treatment. Before treatments were applied to the trees the outline of a square, 2 by 2 inches, was stenciled with white paint on the four sides of each trunk near the ground. Comparison of treatments was made by recording the number of ants in these squares (20 per treatment) at intervals following application. The results are presented in table 1.

The results of this series of experiments show that one application of DDT-fuel oil emulsion applied at the rate of either 16 or 8 ounces DDT per 100 gallons has been very effective in controlling the little fire ant for a period of 4 months, and at the end of this time (November 9) there was no indication that trees were becoming reinfested. It is therefore possible that the treatments will be effective for a considerably longer period. The banding treatments were less effective. The band con-

taining 5 per cent of DDT was as effective as the 10-per cent band, but the 1-per cent band was the least effective of any treatment, even though it was applied twice. Infestation on the check trees was considerably lower on November 9 than on previous dates, but this was due to cooler weather, which ordinarily reduces activity.

In the second series of experiments, five sprays and a dust, all containing DDT, are being compared. Three of the sprays contained DDT dissolved in different oils, and two were water suspensions of a mixture of DDT and pyrophyllite. The dust was prepared by further diluting with pyrophyllite a 10 per cent DDT-pyrophyllite mixture. The experimental set-up for spray treatments was the same as in the earlier experiment, and the dust was applied to 5 trees in a row located near the sprayed blocks. For evaluating the treatments squares were outlined on the trees as described earlier in this paper. The results are given in table 2.

Table 1.—Effect of DDT on the little fire ant, when applied as sprays or bands to grapefruit trees; date of treatment July 7, 1944.

Treatment	Number of Ants				
	July 21	Aug. 5	Aug. 31	Oct. 9	Nov. 9
Sprays, DDT-fuel oil emulsions (quantity of DDT per 100 gal.)					
1 lb.	0	0	0	1	0
8 ounces	0	0	0	1	0
Bands, water paste of DDT in pyrophyllite (per cent DDT)					
10 per cent	81	4	14	18	1
5 per cent	19	4	10	21	0
1 per cent[1]	38	35	6	20	37
Check (untreated)	234	172	328	150	74

[1] Bands reapplied on August 8.

The results of the second experiments show that the best treatment, 4 ounces of DDT in fuel oil, was still effective on the date of the latest count 2 months after application. Other sprays containing equivalent amounts of DDT in light-medium spray oil and as a suspension in water were not so effective. Two ounces of DDT in light-medium oil or as a suspension was inferior to the 4-ounce dosage. The dust containing 1 per cent of DDT was the least effective.

DISCUSSION.—The absence of ants on sampled areas when records are taken is not necessarily indicative of their complete elimination from treated trees. This is particularly true with banded trees.

Table 2.—Effect of DDT on the little fire ant, when applied as sprays or a dust to grapefruit trees; date of treatment September 7, 1944.

Treatment	Concentration of DDT	Number of Ants			
		Sept. 21	Oct. 11	Oct. 24	Nov. 6
	Ounces per 100 gal.				
Sprays, DDT in: Pyrophyllite	4	19	62	4	15
	2	116	114	36	33
6 qts. emulsive spray oil	4	47	24	1	0
	2	17	134	55	56
2 qts. No. 2 fuel oil + glyceryl oleate (10 ml.)	4	0	0	0	0
	Per Cent				
Dust, in pyrophyllite	1	174	97	125	126
Check (untreated)		298	276	232	180

Although the absence of ants on the squares would indicate that few, if any, were crossing the bands, they could be seen on other parts of the trees. Many of them were present when the bands were applied, and, to avoid crossing them, they nested in limb crotches or in other places affording protection. Since it is impossible from a practical standpoint to prevent weeds and grasses from growing up through the trees, ants have undoubtedly gained access in this way without crawling up the trunks.

In both experiments the DDT-fuel oil sprays, containing as low as 4 ounces of DDT in one test, eliminated all ants in the trees at the time of application, and after several months the trees were still practically uninfested. All treatments, with the exception of the dust containing 1 per cent of DDT, reduced the ant populations considerably, but superior results were obtained with sprays of DDT in fuel oil.

No injury to the grapefruit trees that were sprayed, dusted, or banded has been noted. In both experiments it was observed that the sprays destroyed the predaceous ladybeetle *Chilocorus stigma* (Say). However, the regular oil sprays for scale control also kill this insect.—3-10-45.

DDT to Control Potato Insects

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The discovery of DDT as an insecticide of considerable merit needs no further historical commentary except, perhaps, to point out that one of its first uses was for suppression of the Colorado potato beetle, *Leptinotarsa decemlineata*, in Switzerland. The numerous reviews of the Swiss work that have come to our attention have not included information on other insect pests common to potatoes in the United States. It may be assumed that such insects as the potato flea beetle, *Epitrix cucumeris*, the leafhopper *Empoasca fabae*, and some species of aphids are either not present in Europe or are of minor importance.

The first publications in this country dealing with control of potato insects by DDT are those of Granovsky (1944 a, b) who obtained sufficient quantities of DDT to conduct large scale field tests in Minnesota. His results were most encouraging not only because DDT was highly toxic to flea beetles, leafhoppers and tarnished plant bugs but because it also exhibited a remarkable residual effect. Its tenacity after application is a most valuable attribute in potato insect control when heavy and persistent migrations occur from field to field. As a rule insecticide mixtures containing rotenone and pyrethrum, although excellent toxicants, do not prevent or retard reinfestation long enough to be of good value considering cost and effectiveness.

The field testing of DDT for potato insect control in New York has been limited to the past season, (1944) since in 1943 supplies were limited and none was available for field work. More experimental work than at first anticipated was made possible by the cooperation and aid of the Bureau of Entomology and Plant Quarantine who placed at our disposal an additional quantity of DDT powder.[1] The objectives in mind were to obtain some idea of the effect of DDT applications on populations of the various potato insects and some measure of the control for comparison with standard treatments.

At the outset of the work caution was used in applying DDT as there existed a question of phytotoxicity to some crops. Hence, there was a hesitancy to use heavy concentrations on large field plots until the safety factor could be determined satisfactorily. Rather low concentrations were used in the first experiments but dosages were increased as the season progressed.

MATERIALS AND METHODS.—The DDT powder furnished by the Bureau of Entomology and Plant Quarantine was standardized to their specifications of 10 per cent technical DDT milled with pyrophyllite. This concentrate was diluted with *Pyrax ABB* to the concentrations desired for field applications. An insoluble copper, *Compound A*,[2] was added as a fungicide protectant against late blight infection. When sprays were used a suspension of the 10 per cent powder was prepared to which was added a wetting agent *B-1956*.[3]

The upstate experiments were limited to spray comparisons using in this case the proprietary powders *AK 20* and *A 20*[4] with a standard bordeaux mixture. These two materials contain 20 per cent DDT but differ in that the latter, *A 20*, is compounded with a wetting agent. A rotenone extract, *Syntone* was included in the tests for comparison with DDT since some growers have tried rotenone as a supplement in their fungicide sprays. The label stated the rotenone content to be 2.8 per cent but the extract was of a previous year's vintage, having been stored in a dealer's warehouse. Flea beetle kills were as good as could be expected, however, indicating little loss in potency.

Regular field equipment was used for spray and dust applications. Plots of the Long Island experiments were six rows in width and replicated two or more times. A somewhat different system was used in the upstate work in that plots were 30 to 40 rows wide. This plan of plot layout seemed the most feasible way of reducing to a minimum reinfestation by migration of insects from one plot to another. Cross migration over narrow plots which may

[1] Made possible through the efforts of Mr. W. H. White of the Division of Vegetable Insect Investigations.

[2] E. I. du Pont de Nemours & Co.
[3] Rohm & Haas.
[4] Geigy Co., Inc.

give a distorted picture of the effectiveness of treatments is a frequent criticism of this plot design.

Insect populations were estimated from random areas in each plot by net sweeping, a method of rapidity and fair accuracy. Yields were not taken since only one application was made in most of the experiments. A severe drought during the growing season attended by high temperatures retarded plant growth and appeared in some instances to prevent the usual heavy insect infestations.

Table 1.—Control of Colorado potato beetle with DDT in comparison with other insecticides.

Material	Concentration	Per Cent Mortality	
		24 hrs.	72 hrs.
	Experiment 1		
Calcium arsenate	8 lbs. per 100 gal.	76	87
Cube root (4%)	2 lbs. per 100 gal.	85	73
DDT powder (10%)	1.5 lbs. per 100 gal.	75	83
He 761	1 lb. per 100 gal.	83	88
	Experiment 2		
		24 hrs.	48 hrs.
Calcium arsenate	6 lbs. per 100 gal.	56.0	74.7
DDT powder (10%)	1 lb. per 100 gal.	62.7	62.7
DDT-talc dust	0.3%	72.0	73.3
DDT-talc dust	0.5%	96.0	93.3

Results and Discussion.—The first field tests on Long Island were made for Colorado potato beetle control comparing DDT with calcium arsenate, ground cube root and a new synthetic stomach poison designated as He 761 (Rohm and Haas). The concentrations of DDT were low (Table 1), but in effectiveness the DDT compared favorably with the standard arsenical treatment. The synthetic He 761 appeared very toxic to potato beetle larvae producing a good kill with more rapidity than the arsenical. Due to the short infestation period one application was sufficient for practical control thereby allowing no opportunity to observe the residual effectiveness of the various treatments.

Laboratory tests run at Ithaca concurrently with the Long Island work indicated that DDT as a stomach poison was not as toxic as calcium arsenate and as a contact poison not as toxic as rotenone. The same was true for the flea beetle in case of contact action; rotenone gave corresponding kills at much lower dosages. However, the valuation is relative and cannot distract from the possibilities of DDT as a contact and stomach poison.

Long Island growers are more concerned over the damage caused by aphids, *Macrosiphum solanifolii* and *Myzus persicae*, flea beetles and leafhoppers than over control of the potato beetle. Before present scarcities restricted their use, rotenone, pyrethrum and nicotine were increasing in favor as ingredients of potato sprays and dusts. Uncertainty of infestation period and the specificity of these insecticides made practical timing of spray and dust schedules somewhat difficult. It was with considerable interest, then, that DDT was tried to determine its effectiveness in reducing populations of the common foliage feeding insects

Several experiments using a number of concentrations of DDT as dusts were located at different points in the Riverhead area. Insect infestations varied considerably and were exceedingly unpredictable. Estimations of populations were made previous to and 48 hours after application by net sweeping. The populations in the control plots fluctuated during this period so the data from treated plots were adjusted by means of Abbott's formula to correct for increases or decreases of the checks. A summary of data obtained from four experiments showing reductions in populations of aphids, flea beetles and leafhoppers is given in table 2.

The most outstanding revelation from the data is the very effective reduction in populations of all the species of insects common to potatoes on Long Island. DDT reduced the numbers of aphids and flea beetles as well as the standard 0.75

Table 2.—Control of aphids, flea beetles and leafhoppers by various concentrations of DDT in dusts.

Materials	Concentration	Per Cent Decrease in Populations		
		Aphids	Flea Beetles	Leafhoppers
		Experiment 1		
DDT-*Pyrax*	10%	84.3	88.2	87.9
DDT-*Pyrax*	5%	85.9	91.4	89.8
DDT-*Pyrax*	3%	72.8	88.0	65.6
Rotenone-sulfur	0.75%	39.4	77.0	54.1
		Experiment 2		
DDT-*Pyrax*	0.7%	81.9	86.1	—
DDT-*Pyrax*	0.5%	77.9	74.7	—
Rotenone-Sulfur	0.75%	79.6	93.1	—
		Experiment 3		
DDT-*Pyrax*	2%	—	84.0	94.2
Lethane B-71	2%	—	3.0	87.4
		Experiment 4		
DDT-*Pyrax*	0.5%	68.3	90.2	—
DDT-*Pyrax*	0.3%	71.5	70.4	—
DDT *spray*	0.3*	44.5	73.5	—

* Lb. per 100 gals.

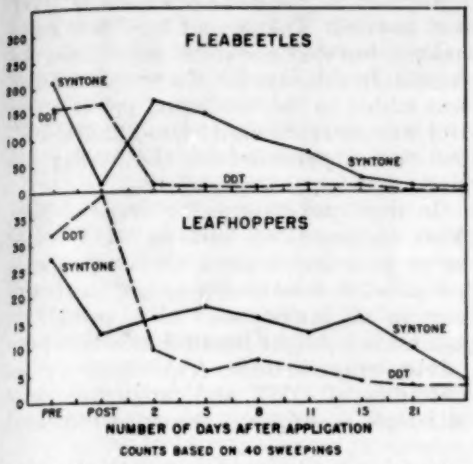

FIG. 1.—Insect populations following an application of *Syntone* and DDT as supplements in the bordeaux spray.

per cent rotenone. Furthermore, it appeared to be highly effective against leafhopper although no pyrethrum was available for a field trial. The new *Lethane B-71* in the single comparison did very well against leafhopper but failed against the flea beetle.

Numerous experiments on Long Island have shown a wide variation in control of potato aphids by either rotenone or nicotine sprays and dusts, although nicotine seems to be more consistent and dependable than rotenone. The average reduction of aphid population is approximately 50 per cent—an apparently poor degree of control but, under normal growing conditions and average aphid populations, is worth while from the standpoint of yields. While it will require a number of years of field work to determine the average level of efficiency for DDT the preliminary data indicate that the dusts with as low a concentration as 0.5 per cent approach the effectiveness of nicotine vapor fumigation, the best method of aphid treatment tried to date. For flea beetle and leafhopper control DDT even in low dilutions gave very promising results. DDT differs from rotenone and pyrethrum in that it has a slower toxic action against these insects.

No conclusive evidence of residual effectiveness could be obtained from the Long Island tests as only one application was applied in all cases except one and no counts were made later than 2 days after treatment. One experiment, started during the early part of the season, for Colorado potato beetle control, was followed through for three additional applications. Populations were determined before and after each 10-day application. The data show no pronounced residual effect as the insect populations increased within a few days after dusting to a point almost equal to infestations in the control plots. The lack of an expected residual effectiveness may be due to the low concentrations of DDT, 0.3 and 0.5 per cent, used. Further work is necessary for definite conclusions on the matter of tenacity.

The western New York experiments were conducted in two areas, Erie and Monroe Counties. Fields regularly sprayed were selected for the experiments; hence, insects were controlled to a considerable extent by the bordeaux spray and populations were not large. In Erie County the DDT was added to one of the regular spray applications made during the first part of September on two small fields. In one case the field was divided in two parts, one division receiving, besides the bordeaux, 1 pound of DDT per 100 gallons of spray, whereas the other half was sprayed with *Syntone* (1–400). The other field was divided into three parts, one being treated with a 10-10-100 bordeaux, one with bordeaux plus *Syntone* and one with bordeaux plus 2 pounds of DDT.

Population counts were taken previous to application, 2 hours after application and at intervals thereafter for 21 days. Four widely separated areas were sampled in each plot at the same approximate loca-

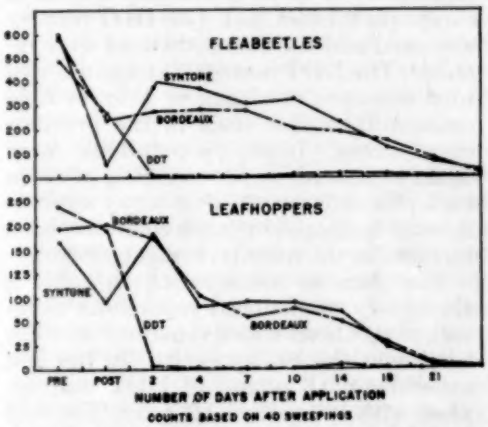

FIG. 2.—Insect populations following an application of bordeaux with and without *Syntone* and DDT as supplements.

tion for each sampling date. The pre-application counts indicated that the infestation of flea beetles and leafhoppers was evenly distributed over the field.

Subsequent counts taken during the three weeks period have been graphically summarized in figures 1 and 2. For the reason that applications were made late in the growing season, populations of insects were on the decline and were nearly absent by the end of the 21-day period. However, it is evident from the data that DDT not only reduced the populations very markedly but also retained its effectiveness over a long period of time. The effectiveness of *Syntone*, on the other hand was temporary, as populations rose sharply within 2 days following application to a point only slightly less than pre-application levels. This observation coincides with previous experience in the use of rotenone as a supplement for potato sprays.

As a check on the mortality that might be expected from DDT and *Syntone* applications, flea beetles were collected from each plot immediately after spraying and caged with untreated foliage. Mortality counts were taken at 24- and 48-hour intervals. DDT was slower in toxic action than rotenone but with the concentrations used the DDT gave as good kills after 48 hours as the rotenone. The rise of populations in rotenone treated plots within a few days after application did not seem to be due to recovery of insects knocked down by the spray. Migration of insects from outlying areas may have accounted for it.

The Monroe County experiments were repetitions of those previously discussed except for the fact that *A-20* DDT powder was used and the concentrations were reduced. The DDT powder was again added to a standard bordeaux of a lower lime content than that used in the previous experiments. Insect populations were again estimated by net-sweeping areas in each plot at intervals after spray applications. A leafhopper nymph count has been included in the records of insect control.

The data as summarized in table 3 show very pronounced reductions in insect populations which remained at a low level over the 10-day period. In the first experiment 0.6 pound of DDT was applied with 100 gallons of spray. The field had been previously well sprayed with bordeaux and insect infestations were lower and on the decline when the DDT was applied. The second field was more heavily infested as can be noted from the counts. In this case 0.8 of a pound of DDT was added to the bordeaux, yet the control was extraordinarily good and the effectiveness persisted for the 10-day period.

In most potato growing areas of New York an insecticide such as DDT would serve as a supplement to the fungicide schedule. It is advisable to use the fungicide in all applications as a protection against late blight because infection periods are unpredictable. A question of compatibility of DDT and fungicides arose although descriptive accounts indicated generally that DDT could be used with all fungicides without restriction. Nevertheless laboratory tests were run on potato flea beetles using a comparative series of insoluble coppers, bordeaux and two organic fungicides. The results of spray tests indicated complete compatibility of DDT with all of the fungicides used in the series. In the case of dusts preliminary trials showed a very significant reduction in toxicity resulting from the use of lime with DDT. This is inconsistent with the findings with the sprays as the lime-containing bordeaux did not affect toxicity. It is evident, therefore, that further work is needed along this line. It appears fairly certain, however, that DDT may be used with bordeaux mixture as effectively as with the fixed coppers.

DDT in concentrations as high as 10 per cent in dust and 5 pounds per 100 gallons as a spray suspension has been safe on potato foliage. Emulsions of *Velsicol* containing 2 pounds of technical DDT per 100

Table 3.—Reduction of flea beetle and leafhopper populations following application of DDT (A-20) in bordeaux sprays.

Time After Spraying	Insects Collected per Sweep of Net				Leafhopper Nymphs per Stalk	
	Flea Beetles		Leafhoppers			
	DDT	None	DDT	None	DDT	None
	First Experiment					
1 day	10.4	12.2	0.8	1.9	0.5	3.2
3 days	2.2	11.0	0.2	1.3	0.1	3.2
7 days	3.5	6.8	0.3	0.1	0.2	0.9
10 days	0.3	0.6	0.1	0.2	0.0	0.0
	Second Experiment					
1 day	4.5	12.9	1.8	3.7	9.4	24.9
3 days	4.6	21.8	0.5	9.3	1.6	7.7
5 days	2.6	39.5	0.5	14.4	0.2	26.1
8 days	3.8	21.5	1.5	10.1	1.0	15.8
10 days	3.8	24.1	0.6	6.9	0.4	16.5

gallons have not caused detectable injury to field grown potatoes. It appears, without doubt, that DDT is perfectly safe at concentrations which will be required for practical insect control.

SUMMARY.—In several trials conducted on Long Island and in western New York DDT appears very promising as a supplement in sprays and dusts for potato insect control. It produced very favorable reductions in infestations of Colorado potato beetle, aphids, flea beetles and leafhoppers. In this performance, if further work confirms the present findings, DDT may prove superior to insecticides now used.

One of the outstanding attributes of this new material, as indicated from the upstate spray tests, was its very pronounced and prolonged residual effectiveness. Insect populations remained at a low level after application for 10 days or more, this being the maximum length of intervals between sprays recommended in the potato spray program. On the other hand, with an opportunity to observe the residual effect in only one experiment, there was no apparent marked tenacity of the dusts on Long Island. This may have been due to low content of DDT in dusts used in this experiment or to an inherent difference between sprays and dusts.

DDT was compatible with the most common fixed coppers, bordeaux mixture and at least two organic fungicides, *Fermate* and *Dithane*. Preliminary trials with dust diluents indicated that hydrated lime was the only one which reduced toxicity. Although DDT was used in concentrations as high as 10 per cent in dusts and 5 pounds per 100 gallons in sprays no plant injury from DDT was evident on field grown potatoes.—1-23-45.

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DDT Aerosols to Control Onion Thrips and Other Pests in Greenhouses

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The dispersion of nicotine and *Lorol* thiocyanate as aerosols for the control of aphids and cyclamen mites in the greenhouse has been reported by Smith & Goodhue (1943) and Goodhue & Smith (1944). This report, which is a continuation of the investigation of aerosols for greenhouse use, includes the results of experiments with DDT (2,2-bis (*p*-chlorophenyl)-1,1,1-trichloroethane) in aerosol form against several species of insects and the tolerance of plants treated in our laboratory greenhouses and in the large greenhouses of the Bureau of Plant Industry, Soils, and Agricultural Engineering, at Beltsville.

MATERIALS AND METHODS.—The aerosol-producing solutions were prepared essentially by methods described by Goodhue & Sullivan (1942) and McGovran *et al.* (1943). Commercial 1-pound aerosol containers were adopted for use in the greenhouse by attaching standard Y-valves to which siphon tubes had been added. The finished containers hold approximately 500 ml. and are similar to those described by Goodhue & Sullivan.

A stock solution was prepared by dissolving commercial DDT in an equal weight of cyclohexanone and filtering to remove insoluble matter. In some cases this solution was mixed with a lubricating oil (S.A.E. 10) and acetone before being introduced into the container. The liquid insecticide was introduced through a funnel screwed into the Y-valve after evacuation of the container. The valve was opened only long enough to draw in the liquid, with little or no air. The propellant, liquid dichlorodifluoromethane

(*Freon-12*), was then introduced through a flexible hose until the desired weight was obtained. If too much was introduced, the excess was removed by allowing some to boil away while the valve was opened in an inverted position. None of the other constituents are lost by this process. Enough extra liquefied gas to supply the saturated vapor above the solution was calculated and included in the total weight that was added.

In previous studies (Goodhue & Smith 1944) capillary tubes of various diameters were used for spraying the aerosol, the rate of delivery being controlled by the diameter and length of the capillary. When aerosols containing DDT were released through a capillary sufficiently small to give proper atomization, the tube often became clogged, especially where corrosion occurred in certain of the containers. A filter of glass wool or wadded cheesecloth or muslin in the line aided in screening out foreign particles. More satisfactory results were obtained with Monarch-type oil-burner nozzles with strainers and having a capacity of 2 gallons per hour. Nozzles of brass or stainless steel did not corrode and were, therefore, preferred to those made of iron or ordinary steel. These nozzles as well as the aerosol containers have been described (Goodhue & Sullivan 1942; McGovran *et al.* 1943).

EXPERIMENTAL PROCEDURE.—The dispensing unit was suspended by a heavy cord from a support above the center walk in the greenhouse and about 6 feet above the floor. For tall-growing plants, as staked tomatoes, the container was suspended about 18 inches above the topmost growth. The string was twisted by rotating the container before opening the valve, so that the container would rotate during the period of release.

By examining glass slides coated with potassium palmitate and placed at different stations throughout the greenhouse, it was determined that a better distribution of the droplets of insecticide was obtained when the air was circulated. To accomplish this, one or two fans, depending upon the size of greenhouse space, were operated at slow speed during the 10-minute period of release and then turned off. It was also determined by the glass-slide method that the droplets of insecticide settled within an hour after release; therefore, the ventilators could be opened, if desirable, after that interval.

The aerosols were released at any time except on sunny days when the ventilators could not be kept closed for an hour after the material had been released because of the rapid rise in temperature, which would be detrimental to the plants.

The writers experienced no ill effects from exposure to the aerosols during or subsequent to the release in the greenhouse, which on several occasions extended over a total of 4 hours in a single day. Any oily solution on the hands resulting from changing or cleaning nozzles was wiped off at once, and no irritation was noted except smarting in cuts or scratches.

EXPERIMENTS WITH VARIOUS FORMULAS.—In making up the aerosols a good solvent for the DDT must be used, together with other materials for controlling the droplet size, improving the kill of insects, and reducing the clogging of nozzles.

In the preliminary experiments a formula containing 3 per cent of DDT (Table I, Formula 1) was used in finding the dosage range for a given greenhouse volume. The results (Table 2, tests 1 to 5) indicate that approximately 1 gram of DDT per 1000 cubic feet should be used to kill a high percentage of adult onion thrips, *Thrips tabaci* Lind., and green peach aphids, *Myzus persicae* (Sulz.). Furthermore, it was found that equal kills of thrips could be obtained with the same dosage of DDT applied in half the quantity of *Freon* (Table 2, tests 5 and 6).

In both formulas 1 and 2 oil was included. In tests 7 and 8 (Table 2) with formulas 3 and 4 it is seen that omission of the oil reduces the effectiveness of the aerosol against both thrips and aphids.

It is evident that increasing the droplet size increases the insecticidal efficiency of the aerosol (McGovran *et al.* 1943). It was found that the maximum and average diameters of droplets were 9.8 and 3.8 microns, respectively, for the aerosol without oil (Formula 3), and 30 and 8.3 microns for the aerosol with oil (Formula 4). In one large greenhouse the number of droplets per square millimeter ranged from 382 near the middle aisle and 10 feet from the nearest dispenser to 230 in a corner 26 feet from the dispenser. The diameter of droplets ranged from 43.4 to 3.5 microns and averaged 11 microns. The largest

Table 1.—Formulas of DDT aerosol solutions used. (Figures refer to percentages.)

FORMULA	DDT	CYCLOHEXANONE	LUBRICATING OIL (S.A.E. 10 OR 30)	ACETONE	METHYLENE CHLORIDE	AROMATIC PETROLEUM SOLVENT	*Freon-12*
1	3	5	5	—	—	—	87
2	6	10	10	—	—	—	74
3	5	10	—	—	—	—	85
4	5	10	10	—	—	—	75
5	5	5	5	5	—	—	80
6	5	10	5	30	—	—	50
7	5	5	5	—	10	—	75
8	5	—	—	—	—	15	80
9	5	5	5	—	—	5	80

droplet (54 microns diameter) was recovered on a glass slide in a greenhouse 26 feet from the dispenser containing aerosol of formula 5.

Later, because it was evident that the cyclohexanone was responsible for injury to such plants as cucumber, acetone was substituted for half of the cyclohexanone (Formula 5), and this formula adopted as the standard for most of the aerosol treatments.

In seven greenhouses at the Bureau of Plant Industry Station, each containing one to four sections ranging in size from 6160 to 65,000 cubic feet, onions are grown from seedlings or bulbs to maturity in an extensive breeding program. The onion thrips scarify the foliage during the winter and spring, and the flower heads as they develop in the spring and summer. Injured flower parts shrivel or fail to set seed. Heretofore, frequent applications of liquid sprays such as tartar emetic and brown sugar or nicotine sulfate in water were required to keep the infestations within reasonable control. These sprays of necessity wetted the lower parts of the plants and encouraged development of botrytis rot, often with resultant loss of considerable numbers of valuable breeding stock. Fumigation with heavy dosages of calcium cyanide killed large numbers of exposed adults but few or none of the larvae in plant interstices.

Following the favorable preliminary tests with DDT aerosols against the onion thrips (Table 2), a control program, consisting of two treatments 5 to 7 days apart with approximately 1 gram of DDT (Formula 5) per 1000 cubic feet, was conducted during February and March in all but one unit in these seven greenhouses. Weekly fumigations with calcium cyanide were continued in this one unit.

At the time the aerosol treatments were started, the onion foliage was becoming conspicuously scarified by thrips and many plants were harboring from 25 to 50 larvae. Following the treatments dead adults and larvae were found clinging to the foliage or on the soil.

The plants developed clean new growth, usually with a sharp zone of demarcation from previously injured areas, and only an occasional living adult and no larvae could be found for 4 to 6 weeks. In the section fumigated with calcium cyanide, thrips injury continued to be serious, adults reappeared, and from 10 to 20 larvae were present on most of the plants at all times. Although adults migrated from this unit into the adjacent aerosol-treated unit,

Table 2.—Results of tests with various aerosol formulas against the onion thrips on onions and the green peach aphid on cabbage. Beltsville, Md., 1944.

TEST AND FORMULA	SOLUTION USED, GRAMS	SIZE OF GREENHOUSE, CU. FT.	DDT, GRAMS PER 1000 CU. FT.	*Thrips tabaci*				*Myzus persicae*	
				Adults		Larvae			
				Number	Per Cent Killed	Number	Per Cent Killed	Number	Per Cent Killed
1—1	100	1,152	2.6	641	99.7	2329	79.3	2504	93.0
2—1	50	1,152	1.3	305	93.4	616	65.1	2549	89.1
3—1	25	1,152	.65	758	74.4	643	40.9	1907	77.1
4—1	1000	24,256	1.25	155	97.8	—	—	—	—
5—1	500	12,128	1.25	134	98.5	—	—	—	—
6—2	250	12,128	1.25	159	96.2	—	—	—	—
7—3	17.3	1,152	.88	332	78.3	94	12.7	1438	47.9
8—4	17.3	1,152	.88	326	100.0	324	76.2	2321	69.1

they were soon killed, evidently by the residue of DDT, and for more than a month no larvae developed from any eggs they might have laid.

HEAVY AEROSOLS.—In April as the onion flower spikes developed and houseflies were confined in cheesecloth cages on the flower heads, the general release of the aerosol in the atmosphere throughout the greenhouses had to be abandoned because of the effect on these pollinators. The houseflies within the cages were killed, and sufficient DDT residue was present on the cloth to affect those introduced subsequent to treatment. Paper bags inverted over the cheesecloth, even with openings 6 inches below the bottom of the cloth, did not give protection to the caged flies.

To protect the onions during the remainder of the season from infestations of thrips that were beginning to build up, a substitute method was employed. In those tests a heavy type of DDT aerosol (Formula 6) was applied directly to the onion plants below the seed head.

It was found that the aerosol could be applied directly to the onion foliage, especially at the junction of the leaf blades with the sheath, without affecting the caged flies on the flower head above. Adult thrips and most of the larvae were paralyzed within a few minutes after treatment and dropped to the ground.

The onions in all seven houses were then treated with the DDT aerosol (Formula 6). The material was placed in pound containers without siphon tubes and fitted with oil-burner nozzles of 1.5-gallon capacity. By inverting the container the jet of aerosol could be directed downward at an angle which reduced chances for upward drift toward the cages. The aerosol was applied rapidly to each side of the rows of plants. One application so reduced the thrips population that no further treatment over the whole range of houses was needed during the succeeding 2 months to harvesting time. An occasional infested plant, possibly imperfectly treated, showed continued thrips injury, and those localized infestations were treated as they were found. As a result of this program the thrips were more efficiently controlled with much less time and effort than when tartar emetic was used, and seed production of individual crosses was much heavier than in previous years. Only an occasional onion plant was lost from bulb rot, whereas in former years losses sometimes exceeded 40 per cent.

The data in table 3 show that the heavy DDT aerosol was superior to the tartar emetic-sugar spray. Furthermore, a single application gave a kill of 98.9 per cent a week after treatment, and two biweekly applications gave a much better protection of the plants from infestations for several weeks than did four weekly treatments with tartar emetic.

Table 3.—Comparison of tartar emetic spray (tartar emetic 2 lb., brown sugar 4 lb., water 100 gal.) and DDT aerosol (formula 6) against the onion thrips.

TREATMENT	NUMBER OF APPLICATIONS	THRIPS PRESENT		PER CENT REDUCTION	EFFECTIVE PERIOD, WEEKS
		Adults	Larvae		
Experiment 1					
Untreated check	—	141	884	—	4
Tartar emetic	4	59	329	52	4
DDT aerosol	4	0	0	100	4
Experiment 2					
Untreated check	—	42	149	—	1
	—	450	1172	—	4
Tartar emetic	1	18	140	17	1
	4	148	572	55	4
DDT aerosol	1	1	1	99	1
	2	35	19	97	4

EFFECT ON OTHER GREENHOUSE PESTS.—The aerosol (Formula 5) with DDT at about 1 gram per 1000 cubic feet was used in a number of other greenhouses against other pests on a wide range of host plants. A single treatment eliminated the onion thrips present on soybeans, while 95 per cent of the adults and 74 per cent of the larvae were killed in flowers of double stocks, *Matthiola incana*. On chrysanthemum plants and also on potted cuttings a single treatment eliminated the chrysanthemum thrips, *Thrips nigropilosus* Uzel, even on plants wet from a leak in the roof. Although a single treatment appeared to be sufficient, two treatments were used to kill out infestations of the banded greenhouse thrips, *Hercinothrips femoralis* (Reut.), on *Rudbeckia* sp. in rosette stage, squill plants of all ages, peppers, and seedling cabbage. Adults and larvae on the under leaf surface of some plants and in curled squill leaves survived normally for 1 or 2 days but were apparently killed by the residue as they moved to exposed surfaces. The population before treatment averaged 30 adults and larvae per leaf on squill; 4 days later there was 1 individual per 55 leaves, the survivors being in curled leaves. Adults of the greenhouse whitefly, *Trialeurodes vapor-*

ariorum (Westw.), on tomato, eggplant, potato, and bean were extremely irritated by the material and flew about before succumbing. The immature stages were not affected by the aerosol, but four weekly treatments in tomato houses killed off adults after they emerged and thereby reduced the populations to a few stragglers.

The percentage of green peach aphids killed within 24 hours by the treatment varied, but on under surfaces of large leaves colonies appeared to be unaffected for several days. However, in 10 to 14 days such colonies on cabbage, *Solanum* sp., and potato almost entirely disappeared. The green chrysanthemum aphid, *Rhopalosiphum rufomaculata* (Wilson), was susceptible to the aerosol treatment, practically all the aphids being killed within 2 days after treatment.

Exposed individuals of the corn leaf aphid, *Aphis maidis* Fitch, on upper leaf surfaces of corn were killed by a dosage of 1 gram per 1000 cubic feet, but those in furled leaves were unaffected.

Adults and nymphs of the cricket *Gryllodes sigillatus* Walk. and of the American cockroach, *Periplaneta americana* (L.), were found dead or paralyzed on the walks or beneath benches on the mornings following aerosol treatments. Since the aerosols were released during daylight hours, when these insects are in hiding, it is evident that they were affected by the residual deposit picked up or with which they came in contact during the night. Adults of uncaged houseflies, *Musca domestica* L., and the fungus gnat, *Lycoria inconstans* (Fitch), in treated greenhouses were quickly paralyzed and killed.

Adults of the citrus mealybug, *Pseudococcus citri* (Risso), on squill were unaffected by the treatment, but younger stages failed to become established and the colonies gradually dwindled, indicating that the active stages were affected by the residue.

Sowbugs (*Armadillidium nosatum* B.L.) sprayed with DDT (Formula 6) became suddenly active and died within 3 days. When heavily infested greenhouse benches were sprayed with this aerosol and potted plants were removed to treated areas, sowbugs present in the gravel died or disappeared.

Individuals fully exposed or hiding in gravel placed in Petri dishes were killed in 1 to 2 days after exposure to a greenhouse treatment with DDT aerosol (Formula 7) with a dosage of 1 gram of DDT per 1000 cubic feet. They were also irritated, paralyzed, and killed by the residue from aerosols 8 and 9 on treated gravel in 1 to 4 days when placed on it in Petri dishes (Table 4).

Table 4.—Effect of DDT aerosols on sowbugs.

Treatment in Petri Dishes	Number of Sowbugs Dead in—				Number of Survivors
	1 Day	2 Days	3 Days	4 Days	
Formula 7:					
Exposed during treatment	169	—	—	—	0
In gravel during treatment	46	53	—	—	0
Formulas 8 and 9:					
Added to gravel 4 hours after treatment	—	73	—	26	1
Added to gravel 48 hours after treatment	—	134	—	8	0
Untreated checks	0	1	1	1	174

Sowbugs, which were very abundant in certain of the greenhouses, gradually disappeared after treatment with formula 5 and were conspicuously absent during the summer although prevalent in adjacent houses.

Red spiders, *Tetranychus bimaculatus* Haw., were unaffected by the aerosol treatments.

EFFECT ON HOST PLANTS.—A large number of host plants, including most of the common commercial greenhouse crops have been treated one to four times with aerosols at dosages of 1 to 2 grams of DDT per 1000 cubic feet, without evidence of injury except on cucumber, tomato, and soybean.

Leaves of healthy cucumber plants (White Spine) were uninjured by 1-gram dosages of DDT in the aerosol. When 2 grams of DDT per 1000 cubic feet in formula 5 were used, the plants developed yellow chlorosis following an aerosol treatment, while mosaic-infected plants were only slightly injured. Tomato plants of all varities beyond the seedling stage were unaffected by one to four exposures of 1 and 2 grams per 1000 cubic feet of DDT in aerosols. In no case was injury observed on seedlings of Bounty and Pan America or its hybrids, but certain lots of seedling Marglobe, Rutgers, Garden State, and Ponderosa developed chlorotic spots on the youngest expanded leaves while other lots of the same varieties were uninjured by two exposures to the same dosages. No injury has been observed on Biloxi soy-

bean in varying stages of growth with 1- or 2- gram dosages of DDT, except in one lot in the first trifoliate leaf stage, which became badly yellowed with a 1-gram dosage but later resumed normal growth. No explanation is offered for the cases of injury on tomato and soybean except possibly the differences in potting soil, other conditions apparently being uniform. Experiments indicate that injury is apparently due to the cyclohexanone in the solution rather than the DDT.

DISCUSSION.—The aerosol method of applying DDT to greenhouse crops has proved effective against several insect pests, but especially thrips and sowbugs. The cost of materials is low, approximately 1 cent per 1000 cubic feet at the present prices. It appears to be safe to the operator and to most plants, and the aerosol may be released in the greenhouse at night or during the day provided weather conditions permit closing the ventilators. The material is effective at the extremes of humidity or temperatures above 60° F. prevailing within greenhouses, and it leaves no visible residue. At intervals the nozzles will require cleaning to remove accumulated DDT or foreign matter, and the aerosol solution should be warmed to at least 70° F. to avoid crystallization during release.

Apparently the DDT is effective both at the time the aerosol is released and also as a residual deposit on the surfaces of plants and other objects. The residual effect is particularly valuable against such pests as roaches, crickets, and sowbugs with nocturnal or irregular habits. Infestations of suceptible insects with great activity would naturally be more completely destroyed by such an insecticide than would the more sluggish species or their less active stages. Although thrips are usually found on the lower leaf surfaces, they also frequent the upper surfaces and thereby come in contact with the DDT residue. It has not been determined whether the single application that destroys an infestation of thrips on such plants as soybeans or chrysanthemums kills the eggs before hatching or the residue kills the young larvae soon after hatching.

The cyclohexanone in the solution evidently acts as an excitant on the insects, increasing their activity and hence their chances for picking up a lethal dosage of the DDT.

The low dosages of DDT in the aerosols dispensed in the onion greenhouses apparently left a sublethal residue on the expanding surfaces of the flower spike with which the caged houseflies came in contact. This possible complication with the usual procedure in pollinating the onion flowers was reduced by the fact that the flower parts are protected in a transparent sheath which splits and everts just before time for pollination, and also that the flies spend their time on the flowers or on the sides and top of the cages.

The heavy aerosols (Formula 6) as applied to the foliage on the flower spikes on which the houseflies were caged, or for control of sowbugs, appears to have value for directing the insecticide into interstices not reached by the lighter aerosol, for treating localized infestations or individual plants, or applying beneath pots for sowbugs, and for reducing chances of disease infection where that is a problem with aqueous insecticides.

SUMMARY.—In greenhouse experiments an aerosol containing 5 per cent each of DDT, cyclohexanone, lubricating oil, and acetone dispensed in dichlorodifluoromethane was found to be highly toxic to the thrips *Thrips tabaci*, *T. nigropilosus*, *Hercinothrips femoralis;* adults of the greenhouse whitefly, *Trialeurodes vaporariorum;* the aphids *Myzus persicae*, *Aphis maidis* and *Rhopalosiphum rufomaculata;* the cricket *Gryllodes sigillatus;* the American cockroach, *Periplaneta americana;* the housefly, *Musca domestica;* the fungus gnat, *Lycoria inconstans;* and sowbugs (*Armadillidium nosatum* B.L.). The material was tested day or night at varying greenhouse temperatures on a wide range of plants, without injury to any except cucumber at high dosages and occasionally seedling tomato and soybean. The injury was traceable to the cyclohexanone. Single aerosol treatments eliminated thrips infestations on chrysanthemums and soybeans, while two treatments were used on onions and squill. By using DDT in a heavy aerosol, thrips on onions were destroyed without affecting housefly pollinators caged on the flowers. The treatments resulted in greater seed production and less botrytis rot than in former years. —1-9-45.

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DDT in Aerosol Form to Control Insects on Vegetables[1]

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Aerosols produced by the liquefied-gas method (Goodhue 1942, Sullivan *et al.* 1942) are now in military use for the control of mosquitoes in combat areas. They have been very successful, and large amounts have been manufactured for this purpose.

The fundamental principle of this method is the release of a solution of insecticide in a liquefied gas into the atmosphere through a small orifice. The aerosol used by the armed forces employs pyrethrum and sesame oil dissolved in liquid *Freon-12* (dichlorodifluoromethane). The particles forming the aerosol are small and remain suspended in the air for long periods without forming a perceptible deposit on surfaces where it is applied. This type of aerosol is adapted for the control of flying insects, but it is not suitable for the control of insects on plants, where larger particles that settle faster and give a good deposit are required. There are numerous variables that influence the properties of the aerosols, and these must be considered before the method can be adapted to the different uses.

Any insecticide soluble in the available liquefied gas can be applied by this method. Liquids are preferred, but solids dissolved in high-boiling solvents can be used if the formation of crystals at the spraying orifice can be prevented. Pyrethrum, rotenone, DDT, organic thiocyanates, and nicotine are some examples.

The most suitable liquefied gases are those in the low-pressure range from 75 to 150 pounds per square inch at room temperature. They include dichlorodifluoromethane (*Freon-12*), chlorodifluoromethane (*Freon-22*), methyl chloride, dimethyl ether, and propane. Methyl chloride and dimethyl ether are good solvents, but the *Freons* and propane are poor solvents for most insecticides. The *Freons* have the advantage of being nontoxic and nonflammable. Although methyl chloride is too toxic to be used in the presence of man or animals in closed spaces, it is an excellent propellent for aerosols to be used in the open on vegetable crops. Carbon dioxide and nitrous oxide have a much higher vapor pressure and require much heavier containers, which would make their use less practical. Some tests show that carbon dioxide is not a good solvent for insecticides.

Oils are important constituents of aerosols. They influence the effectiveness of the insecticide and the physical properties, including the particle size. Some of the oils are good solvents for the insecticides and prevent clogging of the spraying orifice. Some also act as auxiliary solvents when *Freon* is used. Many mineral and vegetable oils have been tested.

Another important constituent of the aerosol to be used for field crops is an organic solvent boiling between 68° and 212° F. This is added in place of some of the liquefied gas to increase the particle size of the aerosol. The inclusion of such a solvent is the most important difference between the aerosol to be used for field crops and the aerosol for space treatment. Acetone has been found to be the most satisfactory solvent.

Any liquid that replaces some of the

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liquefied gas in the formula influences the particle size. This includes the insecticide, the auxiliary solvent, the oil, and any low-boiling solvent. The nonvolatile liquids form droplets that do not diminish in size after formation, but when a volatile solvent such as acetone is added the droplets become smaller as the liquid evaporates. The latter type is most suitable for use on plants, because the proper settling rate and deposit can be obtained without adding enough oil to cause plant injury. These are termed "heavy aerosols" in contrast to "light aerosols" produced by a large proportion of liquefied gas in the solution.

USE OF LIQUEFIED-GAS AEROSOLS IN THE GREENHOUSE.—Aerosols having relatively small particles are easily adapted for greenhouse use in a manner similar to the application of a fumigant. The fine particles distribute themselves well and settle in an hour or two to give a uniform deposit. Smith & Goodhue (1943) showed that nicotine can be applied efficiently with liquid *Freon-12* in the greenhouse, and Goodhue and Smith (1944) also used lorol thiocyanate applied with methyl chloride for the control of cyclamen mites on snapdragons. Methyl chloride, which is somewhat toxic to man, can be used as a propellent where no one is exposed for more than a short period. Some insecticides are either too toxic or too unpleasant to be tolerated by man. These can be applied with a toxic propellent without increasing the hazard.

Recently a large number of experiments with aerosols containing DDT were made in the greenhouse (see p. 173 of this issue). The formula most extensively used contained 5 per cent each of DDT, cyclohexanone, acetone, and lubricating oil, and 80 per cent of Freon-12. Other auxiliary solvents for DDT, such as xylene, orthodichlorobenzene, or aromatic oils, can be used, but cyclohexanone, besides being the best solvent for DDT, has the property of agitating many insects and thus accelerates the killing action of the DDT. The mortality with other combinations may be the same, however. Since too much cyclohexanone will injure some plants, it was necessary to reduce the amount from 10 per cent to 5 per cent and add 5 per cent of acetone to help dissolve the DDT in the *Freon-12*. Lubricating oil was added to give a more effective insecticide.

In the greenhouse experiments the aerosols were applied from containers holding about 500 grams of solution. Both capillaries (0.017 inch in diameter and 1 inch long) and oil-burner nozzles were tried. The oil-burner nozzles were the most satisfactory, because they did not give trouble by clogging. To distribute the insecticide the container is hung on a string in the center of the place to be treated and revolved until the string is tightly twisted before the valve is opened. One container of material will treat 25,000 cubic feet at the rate of 1 gram of DDT per 1000 cubic feet. Since the pressure of a liquefied gas decreases with the temperature, the solution in the container should not be below 70° F. when the treatment is applied. If the temperature is lower, a poor dispersion and clogging of the nozzle will result.

An aerosol of small particle size is best suited for general treatment, but if spot treatments are made, a solution that forms a coarser aerosol should be used. Such solutions contain about 50 per cent of liquefied gas, some of it being replaced with a less volatile material such as acetone.

The insects successfully treated in the greenhouse include the onion thrips, *Thrips tabaci* Lind.; the banded greenhouse thrips, *Hercinothrips femoralis*, (Reut.); the chrysanthemum thrips, *Thrips nigropilosus* Uzel; adults of the greenhouse whitefly, *Trialeurodes vaporariorum* (Westw.); the green peach aphid, *Myzus persicae* (Sulz.); the cricket *Gryllodes sigillatus* Walk.; the American cockroach, *Periplaneta americana* (L.); the fungus gnat *Sciara inconstans* Fitch, and the housefly, *Musca domestica* L. Sowbugs, *Armadillidium* sp., were also very susceptible and were killed by the toxic residue. Among the many plants treated in greenhouses no injury has occurred except on cucumber at excessive dosages, and occasionally on seedling tomato and soybean. That cyclohexanone is responsible for the injury was indicated by the absence of injury when this material was eliminated from the formula or the percentage was reduced.

AEROSOLS ON FIELD CROPS.—For outdoor use on field or garden crops it is obvious that best results with aerosols will be obtained when the mist is coarse enough to form a deposit on the foliage. This is especially true with insecticides

that have a residual action. Moreover, wind reduces the effectiveness of fine floating particles. Several preliminary experiments were made in 1943 by various workers in the Bureau of Entomology and Plant Quarantine, and cylinders of the insecticide were also tested at the University of Maryland. The results appeared promising, and a cooperative agreement was later drawn up to study the application of aerosols to vegetable crops.

Solutions similar to the ones used for the spot treatments in the greenhouse can be applied to field crops. A typical formula is 5 per cent each of DDT, cyclohexanone, and lubricating oil, 35 per cent of acetone, and 50 per cent of methyl chloride. This solution gives a rather wide range in size of particles, most of which are coarse enough to be deposited on foliage. The finer particles, especially with an insecticide such as nicotine, give an effect similar to fumigation while they drift among the foliage, but the killing rate of such fine particles of any insecticide is generally too slow to be of much value.

Methyl chloride, as mentioned early in the paper, is a very good propellent for aerosols to be used out of doors. In comparison with *Freon-12*, it has a much greater solvent action for insecticides, is lighter to handle, and is less expensive. Methyl chloride reacts with nicotine and other organic bases and cannot be used with them.

More than 30 combinations containing DDT, derris resin, and nicotine were tested during 1944. Most of the tests were made on DDT in concentrations from 1 to 10 per cent, with the other constituents in the aerosol mixture, except methyl chloride, varied proportionately. The methyl chloride was generally held at 50 per cent. All solutions were made up on a weight basis. Experiments with these aerosols on the control of the pea aphid and miscellaneous insects are reported elsewhere in this issue (pp. 183, 189).

MACHINES FOR THE APPLICATION OF AEROSOLS.—These field-crop aerosols were applied by light machines which consisted principally of a group of nozzles properly set and spaced on a frame supported by bicycle wheels. The first machine to be built for broadcast crops has six oil-burner nozzles set in two rows under a covered frame 6 feet wide. The front three nozzles are set so that they spray down 45 degrees to the left and backward, while the back three point downward 45 degrees to the right and forward. This arrangement tends to give a whirling action and good coverage. A holder is provided for the tank of solution, which is connected by copper tubes through a filter to the nozzles.

No. 2 nozzles with strainers were used, since smaller nozzles tended to clog during operation. Some difficulty was experienced with pieces of solder in the tubes, but trouble was minimized when both apparatus and solutions were kept clean. Water in the line, corrosion, and precipitates have caused some trouble. The nozzles were flushed with equal quantities of acetone and methyl chloride to clean them after use. Iron nozzles corroded badly with DDT. Brass is not attacked and will therefore be used throughout in the future.

Several other machines were constructed, including a 12-nozzle outfit 12 feet wide for broadcast crops and also a 3-nozzle and a 4-nozzle row crop applicator. The last two machines have a covered chamber to prevent wind drift.

The lead in the construction of these machines has been taken by the University of Maryland,[1] and the information collected on the performance will be of great value when new models are constructed.

RESULTS ON INSECTS.—DDT aerosols have proved effective against about 25 species of insects on vegetable crops in field experiments during 1944. Among the most important pests succumbing to the DDT aerosols were the pea aphid, *Macrosiphum pisi* (Kalt.); the potato aphid, *M. solanifolii* (Ashm.); *Myzus persicae* (Sulz.); *Aphis abbreviata* Patch; the onion thrips, *Thrips tabaci* Lind.; the Colorado potato beetle, *Leptinotarsa decemlineata* (Say); the potato flea beetle, *Epitrix cucumeris* (Harr.); the garden web worm, *Loxostege similalis* (Guen.); the eggplant lacebug, *Gargaphia solani* Heid.; the potato leafhopper, *Empoasca fabae* (Harr.); *Macrosteles divisus* (Uhl.), and *Philaenus leueophthalmus* (L.).

PRACTICAL CONSIDERATIONS.—The aerosol method of applying insecticides, either in the greenhouse or on crops in the open, will have to compete with other

[1] This work is being done under the direction of Prof. George Burkhardt.

methods. If it is more expensive, it must be more effective, be easier to apply, or have other advantages that make its use desirable. At this early stage in the experiments it is difficult to predict how practical the method will be, but the results of the work for this season have shown that DDT and some other insecticides, including nicotine, applied in this way are very effective and in many cases are better than the same insecticides applied by old established methods.

The principles involved in the application of liquefied-gas aerosols are not much different from those which apply to concentrated sprays. The goal to be sought is to apply as concentrated a solution as possible over the largest area and still obtain the desired control of the insects. The higher the concentration of the insecticide in the solution the lower the cost of the treatment will be and the less will be the amount of material to be transported. The rate of application might be increased even to the speed of an airplane. On peas 10 pounds of solution containing 1 pound of DDT per acre has given very good control of the pea aphid. This was applied with a machine moving at the rate of 5 miles per hour. Perhaps a more concentrated solution could be used at a higher rate of speed.

For the control of some insects such as the onion thrips, the aster leafhopper, the eggplant lacebug, and the potato aphid this method appears to be outstanding. The nature of the aerosol is such that it gives maximum contact action and in addition apparently leaves a toxic residue on the plant foliage sufficient to repel or kill migrant leafhoppers. The aerosol treatment gives better results in relation to older methods where dense foliage is encountered. The method would seem to be very practical for truck gardeners, since a rather large area can be treated easily and effectively by a light hand-drawn machine. For larger areas a horse-drawn machine appears to be practical, and for still larger places a tractor or light truck could be used. The four-wheel-drive "jeep" should be excellent for carrying out large-scale commercial treatments.

The success of the method will require the skill and cooperation of manufacturers equipped for the handling of liquefied gases. A different system of handling will be necessary, and some training in the operation of the aerosol-applying machines will be required.—12-15-44.

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EUROPEAN CORN BORER QUARANTINE SITUATION

Because of the spread of the European corn borer into additional counties in Kentucky, Iowa, and Missouri, these States, in November 1944, revoked their quarantines controlling the movement of regulated products from other States and from infested counties within the State. The discovery of 2 specimens of the borer at Kansas City, Kans., during the 1944 summer survey is announced by the Kansas Entomological Commission. The Minnesota infestation is reported by the State entomologist as having spread into 15 additional counties in southeastern and southern Minnesota, since its discovery in Houston County in 1943.

ARIZONA QUARANTINE REVISED

Untreated grapevines may now enter Arizona if certified as originating in a phylloxera-free area, according to a modification of Quarantine Order 3 which became effective January 5, 1945.

Modification of the nut-tree quarantine restrictions of Arizona, which became effective January 5, 1945, reduces the area under regulation and modifies the conditions under which pecan, hickory, and walnut nursery stock may enter the State because of the pecan casebearers. Simultaneously a new quarantine (No. 15) has been placed by the State on the entry of nuts of these three species, requiring treatment or certification as to origin on account of the pecan weevil and the hickory shuckworm.

DDT Aerosols for Pea Aphid Control[1]

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Until the present time the control of the pea aphid, *Macrosiphum pisi* (Kalt.), has been dependent upon the use of two groups of insecticides, the nicotine and the rotenone-bearing materials. These insecticides have been used with varying degrees of success in dusts and ordinary sprays, and more recently in concentrated aqueous and oil sprays (Glasgow 1942) both in aerial and ground machines. Nicotine has been most effectively applied in gaseous form by the Savage (1932) vaporizer (Ditman *et al.*, 1943), the effectiveness of the nicotine being dependent upon its retention around the plants to give a fumigating action. Though experiments for control of the pea aphid have been carried out in various parts of the country since 1899 (Johnson 1899), it was not until after the successful use of derris by Dudley and coworkers (1936) that growers began the practice of regularly treating large acreages of peas for aphid control. Of all the methods of control for the pea aphid, growers generally prefer dusting with rotenone-bearing materials.

Recently Sullivan *et al.* (1942) described a method of applying insecticidal aerosols employing a liquefied gas as a dispensing medium and propellent for soluble toxicants. The simplicity of this method and the high toxicity of insecticides applied in this manner (Smith & Goodhue 1943, Goodhue & Smith 1944) indicate that it may provide a valuable and practical means of combating insects in the field. This paper constitutes a report of the first experiments employing a machine especially constructed for applying aerosols to field crops.

Objectives.—Experiments were carried out on the pea aphid for the purpose of determining (1) the effectiveness of the liquefied-gas aerosol method of insectide application in the field; (2) the comparative effectiveness of varying dosage of nicotine or derris resin and DDT (2,2-bis(*p*-chlorophenyl)-1,1,1-trichloroethane) when applied in aerosol form; (3) the extent of plant injury by the different constituents in the aerosols; and (4) the approximate dosage and the cost of treatments.

Materials and Methods.—The apparatus for applying aerosols to peas consisted of a boom of light angle iron supporting 2-gallon-per-hour oil-burner nozzles located in pairs at 2-foot intervals, fed through ⅛-inch copper tubing, all of which was covered by a light sheet of galvanized iron and mounted on bicycle wheels (Fig. 1). The paired nozzles were about 15

Fig. 1.—Aerosol applicator for treating strips 10 feet in width.

inches apart, the nozzles in the forward row were directed backward to the left at a 45-degree angle, and those in the back row were directed forward 45 degrees to the right. Each nozzle was directed downward at a 45-degree angle. A rack was constructed above the center of the machine to support the aerosol container. It was found desirable to place a filter in the main feed line, close to the aerosol tank. The filter was followed with a valve so that the machine could be cut off without emptying the filter. The bicycle wheels were attached in a manner that allowed raising and lowering of the boom to desired levels for crops 6 to 18 inches in height. Two machines or dispensers were used in this work, one 12 feet wide with 12 nozzles for treating 10-foot strips and an-

[1] Results of a cooperative project between the Bureau of Entomology and Plant Quarantine and the University of Maryland. This constitutes Scientific Paper No. A97, Contribution No. 1937 of the Maryland Agricultural Experiment Station, Department of Entomology.

other 6 feet wide with 6 nozzles for treating 5-foot strips. Aerosol containers of various types were used, ranging from 1 to 15 pounds capacity. These were equipped with valves and attachments for connecting to the main feed line or filter.

In these experiments *Freon-12* (dichlorodifluoromethane) was used as the propellent gas for nicotine, and methyl chloride for the other insecticides. The preparation of solutions and filling of containers were carried out in the same manner as described by Goodhue & Sullivan (1942).

The particle size was controlled by the addition of nonvolatile materials (Goodhue 1943). Aerosols of large particle size obtained by the addition of mineral oil and acetone are termed in this paper "heavy aerosols," while those of small particle size, containing little or no acetone and oil and a high proportion of methyl chloride, are termed "light aerosols." Table 1 gives the formulas included in the field experiments against the pea aphid, together with data on the rate of flow for the various solutions and computed rate of application per acre. With the exception of formula 21, all the aerosols used against the pea aphid were of the heavy type.

The machines were drawn by hand at rates from 2.5 to 5 miles per hour. Applications were made in varying wind velocity both with and without a 15-foot apron or curtain attached to the back of the machine.

EXPERIMENTS AND RESULTS.—Nine experiments involving the control of the pea aphid were conducted in Maryland during the 1944 season, the first four experiments on aphid-infested alfalfa and the remainder on peas.

Experiments 1 to 4 (Table 2) were made to obtain preliminary information of the toxicity to aphids and plants of aerosols containing derris extractives, DDT, or nicotine in several combinations with solvents. The first two experiments were made at the Maryland Agricultural Experiment Station Farm on April 25 and May 3 at temperatures of 64° and 78° F., respectively, a light breeze prevailing. Experiments 3 and 4 were made at the Beltsville Research Center on May 9 and 10 at temperatures of 77° (wind 5 m.p.h.) and 79° F. (wind 5–7 m.p.h.), respectively.

Experiments 1, 2, and 4 were applied to alfalfa plots 10 feet wide and 80 to 100 feet long with the 6-nozzle dispenser equipped with a 15-foot apron and drawn at the rate of 5 miles per hour. Each aerosol in experiment 3 was applied directly from a 1-pound container equipped with a 2-gallons-per-hour oil-burner nozzle and sprayed for 15 seconds, the operator standing in the center of an 8-foot square plot surrounded by a 3-foot-high muslin cloth to prevent drift. In these experiments derris resins gave a relatively low initial kill of aphids (Expts. 1 and 4), nicotine was intermediate (Expts. 3 and 4), while DDT in both 5 and 10 per cent concentrations (Expts. 2, 3, 4) gave high kills without injuring the alfalfa. The lower kill with the 5-per cent DDT in experiment 2

Table 1.—Aerosol formulas used in experiments on the pea aphid during 1944.

Formula	Ingredients in Aerosol, Per Cent by Weight										Pounds Discharged per Minute from a 2-Gallon per-Hour Nozzle	Pounds Applied per Acre at 5 Miles per Hour and 80°F.
	Derris resins (25% rotenone)	DDT	Nicotine	Cyclohexanone	Lubricating oil	Acetone	Ortho-dichlorobenzene	Trichloroethylene	Methyl Chloride	Freon-12		
1	5	—	—	5	5	30	—	—	50	—	0.0967	9.57
2	10	—	—	20	10	20	—	—	40	—	.0915	9.06
3	—	5	—	10	5	30	—	—	50	—	.0945	9.36
4	—	10	—	20	10	10	—	—	50	—	.106	10.5
5	—	10	—	—	10	10	20	—	50	—	.106	10.5
6	—	10	—	—	10	—	—	40	40	—	.119	11.8
7	—	—	10	20	10	10	—	—	—	50	.119	11.8
8	—	—	10	—	20	20	—	—	—	50	.123	12.18
9	—	10	—	—	10	—	20	8	30	—	.119	11.78
18	—	5	—	—	5	40	—	—	50	—	.0915	9.06
19	—	5	—	10	—	35	—	—	50	—	.101	10.0
20	—	5	—	—	—	45	—	—	50	—	.0878	8.67
21	—	10	—	10	—	10	—	—	70	—	.119	11.78
22	—	1	—	2	2	45	—	—	50	—	.0915	9.06
29	—	2.5	—	5	5	37.5	—	—	50	—	.0967	9.57

is probably due to clogging of one of the nozzles during the application. In experiment 4 the DDT aerosols gave uniformly high kills of aphids with all solvents in the four formulas tested.

Experiments 5 to 9 with aerosols were made on peas to test further the toxicity to aphids and the plant tolerance. In experiment 5, conducted on Alaska peas at the Maryland Agricultural Experiment Station Farm at Ridgely, each treatment was applied to four replicated plots 10 feet wide and 205 feet long. The treatments were applied with the 12-nozzle dispenser on the evening of May 15 with wind velocity 1 to 5 miles per hour and temperature 84° F. The speed of application and effect of a 15-foot curtain were stressed in this experiment. The results in table 3 show a low percentage reduction of aphids 4 days after treatment by the derris-resin and nicotine aerosols, while the DDT aerosols were equal to or better than the standard derris-powder spray. While the yields of all plots were small, it appeared that the treatment resulted in increased yields when compared with the untreated checks. The high toxicity of the DDT aerosols in all plots did not show differences between rates of application or with and without the use of a trailer curtain. The injury by the DDT aerosols consisted in occasional spotting of the lowest leaves, while that by the nicotine aerosol consisted in browning of margins of some topmost leaves.

In experiment 6, on Alaska peas at the Beltsville Research Center, treatments were applied on May 18 with the 6-nozzle dispenser and the 15-foot curtain at the rate of 5 miles per hour with temperature 74° F. and wind velocity 3 to 5 miles per hour. Each treatment was applied to three replications in a random block arrange-

Table 2.—Results of aerosol treatments on alfalfa fields in Maryland Experiments 1–4.

Active Ingredient		Formula	Aphids per Sweep: Before Treatment	Aphids per Sweep: After Treatment: 1 Day	2–3 Days[1]	6–7 Days[2]	Reduction, Per Cent of Check, After—[3]: 2–3 Days	6–7 Days
				Experiment 1				
Checks (3)	—	—	73	—	122	310	—	—
Derris resins	5%	1	68	—	96	265	21	14
	10	2	93		55	84	55	73
				Experiment 2				
Checks (2)	—	—	216	588	—	1440	—	—
DDT	5%	3	344	131	—	343	—	76
	10	4	274	63	—	66	—	95
				Experiment 3				
Check (1)	—	—	—	212	413	—	—	—
DDT	10%	4	—	30	14	—	97	—
		5	—	137	68	—	83	—
		6	—	78	39	—	90	—
Nicotine	10%	7	—	113	135	—	67	—
				Experiment 4				
Checks (7)	—	—	—	200	185	88	—	—
Derris resins	10%	2	—	140	121	26	35	70
DDT	5%	3	—	7	1	2	99	98
	10	4	—	22	3	3	98	97
	10	5	—	8	2	3	99	97
	10	6	—	8	1	1	99	99
Nicotine	10%	7	—	49	46	64	75	27

[1] Experiment 3 checked 2 days after treatment, experiments 1 and 4 on the third day.
[2] Experiments 1 and 2 checked 6 days after treatment, experiment 4 on the seventh day.
[3] Per cent reduction in this and the following tables was based on the formula:

$$\frac{\text{Number of aphids in check after treatment} - \text{number of aphids in treatment}}{\text{Number of aphids in check after treatment}} \times 100.$$

ment of plots each 5.5 by 80 feet. Various solvents for DDT and nicotine in the aerosols were compared in this experiment. It may be seen from table 4 that all DDT aerosols were highly effective against the pea aphid and that the nicotine was somewhat less so. The orthodichlorobenzene combinations in formulas 5 and 9 caused moderate to severe plant injury, while the nicotine caused slight injury.

In experiment 8, treatments with the 12-nozzle dispenser, without the curtain, were applied to wrinkled peas in plots 20 by 200 feet on the Tyce Farm at Grantsville, Md., on June 30, at 5 miles per hour. The temperature was 70° F., and the wind velocity 10 to 20 miles per hour. Further tests with various combinations of solutions and with reduced dosages of DDT were made in this experiment (Table 6). As in experiment 7, the need for either cyclohexanone or oil in the formula was not demonstrated (formulas 3, 18, 19, 20). Reduction of DDT to 1 per cent (formula 22), or of the amount of 2.5 per cent DDT applied by closing half of the nozzles, only slightly reduced the percentage kill of aphids. The drift of the aerosol to untreated areas is indicated by comparison of the population trends in untreated checks 1 and 2, which were located to the leeward side of plots treated with formulas 29 and 4, respectively. The drift from the latter with a heavier application of DDT apparently had a more decided effect on reduction of aphids in check 2. Many dead aphids were noted on the

Table 3.—Results of aerosol treatments on Alaska peas, Ridgely, Md. Experiment 5.

Active Ingredient		Formula	Speed of Application, M.P.H.	Curtain	Aphids per Sweep				Reduction, Per Cent of Check, May 19	Yield of Shelled Peas, Pounds per Acre
					Before Treatment	After Treatment				
					May 15	May 19	May 25	May 30		
Check	—	—	—	—	56	175	589	778	—	310
Derris spray[1]	—	—	3.5	No	46	9	24	103	95	528
Derris resins	5%	2	2.5	Yes	47	33	78	158	81	602
DDT	5%	3	5.0	Yes	46	10	25	100	94	600
	10%	4	2.5	Yes	53	16	28	63	91	560
				No	57	14	22	112	92	630
			5.0	Yes	47	8	40	79	95	653
				No	53	11	34	71	94	566
Nicotine	10%	8	2.5	Yes	48	23	115	243	87	439

[1] Ground derris root (6.3 per cent rotenone) 2.5 pounds, sodium lauryl sulfate 0.25 pounds, water 100 gallons.

In experiment 7 at Westminster, Md., on a variety of wrinkled peas, treatments were applied on June 6 with the 6-nozzle dispenser, without the curtain, at 5 miles per hour. Duplicate plots 10 by 80 feet were used for each treatment. The aphid population averaged 85 per sweep before treatment. The temperature was 80° F. with wind 3 to 5 miles per hour. The effect of varying the proportions of oil, cyclohexanone, and acetone was observed in this experiment (Table 5). It appears that the aerosols with higher proportions of acetone are slightly more effective and the need for either oil or cyclohexanone is not demonstrated (formula 20). Of interest is the high kill obtained with only 2.5 per cent of DDT in formula 29.

Table 4.—Results of aerosol treatments on Alaska peas, Beltsville Research Center. Experiment 6.

Active Ingredient		Formula	Aphids per Sweep		Reduction, Per Cent of Check, May 22
			Before Treatment May 18	After Treatment May 22	
Checks	—	—	102	200	—
DDT	5%	3	129	10	96
	10%	4	142	4	98
		5	125	2	99
		9	146	7	97
Nicotine	10%	8	119	42	84

Table 5.—Results with DDT aerosols on peas, Westminster, Md. Experiment 7.

Per Cent of DDT	Formula	Aphids per Sweep June 9	Reduction, Per Cent of Check, June 9
Check	—	115	—
5	3	32	72
	18	17	85
	19	14	88
	20	14	88
2.5	29	28	75

ground in check 2 on the day following treatment.

Table 6.—Results with DDT aerosols applied to peas, Grantsville, Md. Experiment 8.

PER CENT OF DDT	FORMULA	APHIDS PER SWEEP: Before Treatment June 30	APHIDS PER SWEEP: After Treatment July 3	REDUCTION, PER CENT OF CHECK,[1] JULY 3
Check 1	—	306	264	—
Check 2	—	292	79	—
5	3	264	13	92
10	4	153	9	95
5	18	203	14	92
	19	310	20	88
	20	185	22	87
10	21	202	12	93
1	22	338	40	77
2.5	29	470	25	85
2.5[2]	29	198	27	84

[1] Based on average of the checks.
[2] In this treatment half the quantity of aerosol was applied by shutting off the back row of nozzles.

Experiment 9 was made on July 1 in the same field with the preceding experiment. Treatments were applied to single plots each approximately 1 acre in area. The sprays were applied with a commercial sprayer at 600 pounds pressure, and the aerosol was applied with the 12-nozzle applicator. The temperature was approximately 75° F., and the wind velocity slightly exceeded 5 miles per hour. The results obtained by 10-sweep samples from each plot (Table 7) showed that the DDT spray was somewhat better than the standard derris-powder spray and that DDT aerosol was much more effective in rapidly reducing the aphids. The lower effectiveness of derris-powder sprays on dense growth of the wrinkled peas has been recognized, but the DDT aerosols appear to be effective even under these conditions.

DISCUSSION.—One year's work under varying conditions of plant vigor and weather has demonstrated that the aerosol method of applying some insecticides is highly effective against the pea aphid in the field. DDT aerosols have equaled or surpassed rotenone-bearing sprays in reducing aphid populations, especially on heavy growth of wrinkled peas. DDT was more rapid in its action when applied in aerosol than in an aqueous spray. Aerosols containing 10 per cent of nicotine showed considerable effectiveness against the pea aphid but caused injury to both peas and alfalfa and were very irritating to the operators. Aerosols containing derris resins did not compare favorably with sprays of the ground derris root.

While low concentrations of DDT were highly effective against the pea aphid, the optimum concentration of DDT in heavy aerosols appears to be about 5 per cent. Little reduction in cost is gained by reducing this percentage, and small increase in effectiveness is gained by increasing the DDT content to 10 per cent. The solvents appear to be unimportant at the concentrations of DDT used in these experiments. Large-scale commercial tests should be made before the most desirable DDT concentration is decided upon.

Some of the DDT aerosols caused slight injury to the pea plants. Occasional leaves particularly on Alaska peas of low vigor, developed small brown spots, and some of the aerosol mixtures gave a slight yellowish-green appearance to treated plots. Injury occurred most often where plants came in close contact with the jet from the

Table 7.—Comparison of DDT and derris against the pea aphid on peas, Grantsville, Md.

TREATMENT	APHIDS PER SWEEP: Before Treatment July 1	APHIDS PER SWEEP: After Treatment July 3	APHIDS PER SWEEP: After Treatment July 16	REDUCTION, PER CENT OF CHECK, JULY 3
Aerosol:				
DDT 5% in formula 3	768	54	40	93
Sprays:				
DDT (10%) 8 lbs., sodium lauryl sulfate 2 oz., water 100 gal.	944	312	165	67
Derris powder (2.5% rotenone) 6 lbs., sodium lauryl sulfate 4 oz., water 100 gal.	930	457	200	51

nozzle, and was more noticeable in Alaska peas of low vigor than in wrinkled peas. Injury was attributed to the use of orthodichlorobenzene (most severe) and to excessive amounts of oil or cyclohexanone. In no instance did injury appear to be so severe as to reduce the yield of peas; it could be detected only with difficulty a week after treatments were applied except when orthodichlorobenzene was a component.

Little mechanical difficulty was experienced in the application of the DDT and nicotine aerosols. A tendency of derris to clog the nozzles, particularly when 10 per cent of derris resins was used, was due to the continuous formation of insoluble dehydro compounds. Therefore derris resins did not prove very satisfactory for this method of application. The use of a filter and noncorrosive nozzles, combined with the practice of flushing the machines after use with methyl chloride-acetone solutions, solved most mechanical difficulties.

In these experiments the cost of these DDT aerosol treatments compares favorably with the cost of spraying or dusting with rotenone materials. Moreover, the equipment for their application is simple, light, and relatively inexpensive.

SUMMARY.—In one season's work DDT applied by the liquefied-gas aerosol method was highly effective against the pea aphid on alfalfa and on Alaska and wrinkled peas. DDT applied in this manner was rapid in action and gave a kill of aphids equal or superior to standard sprays of ground derris root or sprays of an aqueous suspension of DDT. Aerosols of derris resins did not give favorable results, while the nicotine aerosols, though giving fair kills, caused injury to alfalfa and pea plants. About 5 per cent of DDT appears to be the optimum concentration for use against the pea aphid, and good results were obtained with several combinations of the solvents cyclohexanone, lubricating oil, and acetone, with 50 per cent of methyl chloride as propellent. DDT aerosol treatments compare favorably in cost with standard treatments and in addition are applied with simply constructed inexpensive equipment.—1-9-45.

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FEDERAL QUARANTINE REVISIONS

Federal domestic plant quarantines pertaining to the white-fringed beetle and the pink bollworm were revised in November 1944, chiefly for the purpose of extending the regulated areas to include additional districts or counties found infested during the season.

The black stem rust quarantine was revised to add the State of Washington to the list of States that are being protected from the rust by restricting the movement thereto of susceptible species of barberry and mahonia plants.

Experiments with Aerosols Against Some Pests of Truck Crops[1]

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During 1944 studies were conducted with aerosols against several pests attacking truck crops growing either in small field plots at the Beltsville Research Center or in commercial plantings in Maryland or Maine. The object of these experiments was to determine the toxicity of aerosols containing DDT, derris extractives, and nicotine to these pests; to compare the efficiency of various aerosol formulas; and to check on plant tolerance. Experiments with aerosols against the pea aphid on alfalfa and peas are reported in another paper (see p. 183).

MATERIALS AND METHODS.—Four aerosol dispensers, designed for experiments on the various types of crops, were used in these investigations. In general each machine consisted of a frame of angle iron or pipe covered with sheet iron or muslin and mounted on bicycle wheels, with a support for the aerosol container and connections leading to the nozzles. The specific designations of the three most used dispensers are as follows:

(1) A 3-nozzle dispenser suitable for narrow row crops, as onions or gladiolus, and not adjustable in width.

(2) A 4-nozzle dispenser of pipe and angle-iron frame, which is adjustable in width, also in position and angle of nozzles. In most experiments two 8-foot poles were fastened to the upper outside standards of the frame and allowed to extend backward. A light muslin canopy covered the top and sides of the machine, extended out over the poles, and touched or dragged on the plants in the rear. The front opening above the plants being treated was covered with muslin to reduce the air currents during operation.

(3) A 6-nozzle machine suitable for broadcast crops such as peas or spinach or low-growing, closely planted row crops as lettuce or onions. In some experiments a canopy was used as described for the 4-nozzle dispenser.

The aerosols as described in table 1 were prepared for field use in 2- or 5-pound containers, according to the methods of Goodhue & Sullivan (1942) and Smith and Goodhue (see p. 173).

The effects on the insects were determined by examinations in the field or by observations of collected samples taken to the laboratory.

ONION THRIPS.—In experiments against the onion thrips, *Thrips tabaci* Lind., three DDT aerosols were applied to white Portugal onions grown in rows 10 inches apart on farms near Westminster, Md. The treatments were made with the 6-nozzle dispenser without curtain or canopy at the rate of 3.5 miles per hour, on June 6 and 21 with wind velocities 5 and 8 miles per hour and temperatures 72° and 76° F., respectively. The treatments were compared by examination of 10 plants in each of two replicates of each treatment and the checks. The results of the examination on June 9 (Table 2) show that a single treatment with a 5 per cent DDT aerosol (Formula 3) or a light 10 per cent DDT aerosol (Formula 21) is less effective than a heavy 10 per cent DDT aerosol (Formula 12). The light aerosols include higher proportions of the propellent gas and deliver finer particles of insecticide than the heavier aerosols. These differences were still apparent on June 21 in the first experiment but not in the second. After the second application on June 21 there was little difference between any of the treatments. The counts on July 8 in experiment 2 showed a greater reduction of larvae than of adults on the treated plots, indicating that breeding was reduced by all treatments and that the adults were migrating into the treated plots from untreated checks.

Although the toxicity of the aerosol to the thrips was well demonstrated in these

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The writers acknowledge the assistance of Geo. J. Burkhardt, of the Department of Agricultural Engineering, University of Maryland, in constructing the machines used in applying the aerosols; of T. E. Bronson, of the Bureau of Entomology and Plant Quarantine, in conducting the tests on potatoes in Maine and of W. R. Ballinger, also of this Bureau, in preparing and applying the aerosols.

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Table 1.—Summary of aerosol formulas used against pests of truck crops.

Formula	Ingredient of Aerosol, Per Cent by Weight												Pounds Discharged per Minute from No. 2 Nozzle at 80° F.	Pounds Applied per Acre[1]
	Derris Resin (25 per cent rotenone)	DDT	Nicotine	Nicotine Copper Ammino-oleate	Cyclohexanone	Lubricating Oil	Acetone	Trichloroethylene	Deodorized Kerosene	Methylene Chloride	Methyl Chloride	Freon-12		
3	—	5	—	—	10	5	30	—	—	—	50	—	0.094	9.36
4	—	10	—	—	20	10	10	—	—	—	50	—	.106	10.5
10	—	5	—	—	5	5	35	—	—	—	50	—	.101	10.0
11	—	5	—	—	—	5	5	—	—	—	85	—	.119	11.8
12	—	10	—	—	10	10	20	—	—	—	50	—	.110	10.80
13	—	10	—	—	10	10	—	—	—	—	70	—	.123	12.18
14	—	10	—	—	—	10	30	—	—	—	50	—	.101	10.0
15	—	10	—	—	—	10	—	—	—	20	60	—	.123	12.18
16	—	10	—	—	—	10	—	30	—	—	50	—	.123	12.18
17	—	10	—	—	—	—	—	—	20	20	50	—	.110	10.89
18	—	5	—	—	—	5	40	—	—	—	50	—	.092	9.06
19	—	5	—	—	10	—	35	—	—	—	50	—	.101	10.0
20	—	5	—	—	—	—	45	—	—	—	50	—	.088	8.69
21	—	10	—	—	10	—	10	—	—	—	70	—	.119	11.78
22	—	1	—	—	2	2	45	—	—	—	50	—	.092	9.06
23	—	5	—	—	—	10	35	—	—	—	50	—	.097	9.57
24	5	5	—	—	5	10	25	—	—	—	50	—	.114	11.29
25	5	—	—	—	—	10	35	—	—	—	50	—	.088	8.69
26	—	—	5	—	—	—	—	—	—	—	—	95	.140	13.87
27	—	—	5	—	—	10	—	—	—	—	—	85	.136	13.44
28	—	—	—	10	—	—	—	—	—	—	—	90	—	—
29	—	2.5	—	—	5	5	37.5	—	—	—	50	—	.097	9.57
30	2	2	—	—	2	10	34	—	—	—	50	—	.097	9.57
31	—	10	—	—	—	10	30	—	—	—	50	—	.092	9.06

[1] Computed for 6-nozzle dispenser at 80° F. and operation at speed of 5 miles per hour.

two field experiments, the yield of bulbs harvested on July 14 showed no differences between treated plots and the checks. Apparently the thrips built up to injurious numbers too late in the growing season to affect the yield, as Hawthorn (1943) showed by removing onion foliage at different stages of growth in an effort to determine losses due to hail injury.

At the Beltsville Research Center, an experiment was made with a heavy 5 per cent DDT aerosol (Formula 10) applied at the rate of 3 miles per hour against a heavy infestation of the onion thrips on 25-bulb plots of Ebenezer onions replicated five times. The time and number of applications were varied, and a comparison was made with the generally used tartar emetic-sugar spray. The results, based on appearance of foliage and yield of bulbs at maturity, are given in table 3. All treated plots yielded better than the checks, but by an analysis of variance only two of the aerosol treatments (Nos. 2 and 3) and the tartar emetic spray (No. 5) showed significant differences as compared with the check. There were no real differences between treatments. The foliage of checks was severely injured and dwarfed, and died prematurely, that on

Table 2.—Effect of DDT aerosols on population of onion thrips on onions. Aerosols applied June 6 and 21. Westminster, Md.

Concentration of DDT, Per Cent	Formula	June 9		June 21[1]		June 27		July 8		
		Thrips per Plant	Per Cent Reduction	Thrips per Plant	Per Cent Reduction	Thrips per Plant	Per Cent Reduction	Thrips per Plant	Per Cent Reduction	Per Cent Reduction of Larvae
Experiment 1. Farm of Ray Hook										
Untreated check	—	13.8	—	29.2	—	107.3	—	—	—	—
5	3	2.3	83.3	9.1	68.8	4.6	95.7	—	—	—
10	12	.6	95.6	3.5	88.0	.5	99.5	—	—	—
	21	2.6	81.2	7.4	74.6	2.1	98.0	—	—	—
Experiment 2. Farm of Howard Gorsuch										
Untreated check	—	15.0	—	28.5	—	44.3	—	520.3	—	—[2]
5	3	1.4	89.2	2.9	89.8	1.8	95.9	61.5	88.2	98.6
10	12	.3	97.7	2.3	91.9	.3	99.3	36.1	93.1	99.0
	21	.8	93.8	1.5	94.7	.0	100.0	36.7	92.9	99.4

[1] Counts made before second treatment was applied.
[2] 250.8 larvae per plant.

Table 3.—Yield of onions in small plots treated with DDT aerosol or tartar emetic spray. Beltsville, Md.

No.	Treatment	Dates Treated	Average Yield per Plot, Ounces
1	5% DDT aerosol (formula 10)	June 16	39.4
2	5% DDT aerosol (formula 10)	June 1 and 16	43.9
3	5% DDT aerosol (formula 10)	June 1, 16, and 29	46.9
4	5% DDT aerosol (formula 10)	June 1, 8, 16, 22, 29, and July 5	40.7
5	Tartar emetic spray[1]	June 1, 8, 16, 22, 29, and July 5	47.5
6	Water check	—	31.9
Difference required for significance at odds of 19:1			11.2

[1] Tartar emetic, 2 lb., white sugar 4 lb., water 100 gal.

plots treated only on June 16 (No. 1) was little better than the checks, while that on plots treated two, three, or six times (No. 2, 3, or 4) were uniformly free of injury. The tartar emetic spray caused slight but general silvering. From this experiment biweekly treatments with an aerosol appeared to be adequate for protecting the foliage from thrips injury.

In another experiment with nine DDT aerosols (Formulas 3 and 10–17) on small plots of onions, all except formulas 16 and 17 gave uniformly good control of thrips. A white deposit due to crystalline DDT was evident on foliage of plants treated with these two aerosols. Feeding was greater on foliage treated with formula 17 than on any of the other plots.

POTATO FLEA BEETLES.—Plots in an extremely heavy infestation of potato flea beetles, *Epitrix cucumeris* (Harr), in a field of Katahdin potatoes near Houlton, Maine, were treated on August 12 at temperatures near 100° F. The insects were almost immediately affected by the DDT aerosols, dropped to the ground, and were dead when examined 24 hours later. The nicotine aerosols stupefied the flea beetles, but many recovered later.

Table 4 compares the results of several treatments on the basis of the survivors found on 25 terminals in each plot.

All the DDT aerosols were highly efficient. The nicotine aerosol (Formula 26) was partially effective when applied with the 4-nozzle row machine but ineffective with the 6-nozzle dispenser. The nicotine-copper ammino-oleate (Formula 28) apparently killed none of the flea beetles. The 4-nozzle row dispenser was slightly more effective than the 6-nozzle machine (Formulas 12 and 13), probably owing to better coverage on the lower leaf surface The results with the 6-nozzle machine also indicated that the heavy aerosol in formula 12 is slightly more effective than the lighter one in formula 13, also that a curtain adds to the effectiveness of the treatment. The greater efficiency of the 4-nozzle machine resulted in high kills of flea beetles even with the light and heavy aerosols containing 5 per cent of DDT (Formulas 10 and 11). The 5 per cent DDT aerosol gave better kills than when derris resins were added (Formulas 10 and 24).

TARNISHED PLANT BUGS.—DDT aerosols applied on potato plants at Houlton, Maine, stupefied tarnished plant bugs, *Lygus pratensis* (L.) within a short time, and a high mortality occurred within 24 hours, whereas the derris and nicotine aerosols were less effective or gave no kill (Table 4).

Table 4.—Effect of aerosols on potato flea beetles and tarnished plant bugs on Katahdin potatoes. Houlton, Maine.

Active Ingredient	Formula	Number of Nozzles	Curtain	Surviving	
				Flea Beetles	Tarnished Plant Bugs
Untreated check	—	—	—	431	16
DDT 10%	12	4	Yes	4	0
			No	4	0
		6	Yes	20	0
			No	30	3
DDT 5%	10	4	Yes	9	0
			No	9	0
	11	4	Yes	8	0
			No	12	0
DDT 10%	13	4	Yes	7	0
			No	15	0
		6	Yes	40	2
			No	71	5
DDT 5% and derris resins 5%	24	4	Yes	53	10
			No	79	1
Nicotine 5%	26	4	Yes	151	14
		6	Yes	448	24
Nicotine copper ammino-oleate 10%	28	4	Yes	325	37

SPITTLE BUGS.—Adults of the spittle bug *Philaenus leucophthalmus* (L.) in peas at Grantsville, Md., were evidently affected by the DDT aerosols applied for control of pea aphids even at the 1 per cent concentration (Formula 22). While a few survivors occurred in the plots treated with aerosols containing 5 per cent or less of DDT, none were collected in plots treated with 10 per cent DDT aerosols (Table 5). The results were based on adults collected with the pea aphids by 10 sweeps of the net in each plot.

Table 5.—Effect of DDT aerosols on populations of spittle bugs and syrphid larvae on peas. Grantsville, Md.

Concentration of DDT, Per Cent	Formula	Spittle Bugs		Syrphid Larvae	
		Before Treatment	3–5 Days after Treatment	Before Treatment	3–5 Days after Treatment
1	22	13	2	3	3
2.5[1]	29	13	1	1	4
5[1]	3	8	2	4	3
	18	10	2	1	5
	19	12	0	3	0
	20	17	0	4	5
10	12	13	0	2	3
	21	27	0	6	8
Checks:					
Untreated[1]	—	18	17	5	9
DDT spray[2]	—	4	1	11	18
Derris powder spray[3]	—	5	3	4	9

[1] Average of 2 replicates.
[2] DDT (10%) 8 lb., sodium lauryl sulfate 2 oz., water 100 gal.
[3] Derris powder (2.5% rotenone) 6 lb.-sodum lauryl sulfate 4 oz., water 100 gal.

ASTER LEAFHOPPERS.—On September 8, 49 adults and nymphs of the aster leafhopper, *Macrosteles divisus* (Uhl.), were collected by making 30 sweeps with the net from well-headed lettuce in the experimental fields at the Plant Industry Station of the Beltsville Research Center. Two DDT aerosols (Formulas 10 and 12) were then applied with the 4-nozzle dispenser with canopy and operated at a speed of 3.8 miles per hour. No leafhoppers were found in 30 sweeps after 1 day or in 50 sweeps after 3 days; on the respective untreated check plots 67 and 71 leafhoppers were collected. Following these favorable results, on September 11, the entire field was treated with the 5 per cent DDT aerosol (Formula 10) in an effort to protect the crop from further spread of the aster yellows virus. Only 2 adults were collected by sweeping 50 to 200 times on each of the following days: September 15 and 27 and October 3, 10, and 17.

GARDEN WEBWORMS.—Tests with three aerosols were made against the garden webworm, *Loxostege similalis* (Guen.), severely damaging large areas of spinach near Baltimore, Md. The treatments were made with the 6-nozzle dispenser with the muslin canopy supported by poles at the rear. Each aerosol was applied to two plots of one-third-grown spinach on September 20, and one aerosol was applied to a single plot of nearly mature spinach. Each treatment was made at a speed of 3.8 miles per hour, temperature being 77° F. and the wind velocity less than 5 miles per hour. The machine was adjusted so that the nozzles just cleared the plants.

The efficiency of the treatments was measured by examining 100 plants in each plot for surviving larvae 48 hours after application, or a total of 200 plants for each treatment. As indicated in table 6, DDT aerosols gave a high reduction of the living larvae in the young spinach, and the formula tested on more mature plants was equally effective. The derris aerosol was very inefficient. The DDT aerosols were considerably more effective against this insect than was a commercial pyrethrum dust containing 0.2 per cent of pyrethrins, which was applied with a traction duster at the rate of 50 pounds per acre to areas contiguous to the aerosol plots. The pyrethrum dust resulted in a 53.8 per cent reduction of larvae.

Table 6.—Effectiveness of aerosols against larvae of the garden webworm on spinach. Baltimore, Md.

Toxic Ingredient in Aerosol	Formula	On ½ Grown Plants		On Nearly Mature Plants	
		Surviving Larvae	Per Cent Reduction	Surviving Larvae	Per Cent Reduction
Untreated check	—	65	—	160	—
DDT 10%	12	5	92.4	9	94.4
DDT 5%	10	4	93.9	—	—
Derris resins 5%	25	54	16.9	—	—

EGGPLANT LACEBUGS.—Three experiments were made with aerosols against the eggplant lacebug, *Gargaphia solani* Heid., on plantings of large eggplants in the vicinity of Beltsville, Md. The 4-nozzle dispenser with 8-foot muslin canopy was operated in experiment 1 at 2.7 miles per hour at 72° F. and wind velocity near 20 miles per hour, and in experiments 2 and 3 at 3.8 miles per hour at 76° F. with wind velocity about 5 miles per hour.

The adults and nymphs began dropping to the ground soon after the DDT aerosol was applied and were dead by the following day. After application of the nicotine, all were on the ground within 2 minutes but apparently recovered by the next day. No knock-down or kill was obtained with the derris aerosol. In experiment 1 the three DDT aerosols were all highly efficient (Table 7), but some eggs hatched later. At those dosages no difference in effectiveness between aerosols with large

Table 7.—Comparison of various aerosols against the eggplant lacebug on eggplant. Beltsville, Md.

Active Ingredient	Formula	Experiment	Number of Survivors[1]		Per Cent Reduction
			Adults	Nymphs	
Untreated checks	—	1	201	536	—
		2	1324	467	—
		3	172	1160	—
DDT, 10%	12	1	1	0	99.9
		2	0	8	99.5
		3	8	50	95.6
DDT, 5%	10	1	10	3	96.9
DDT, 10%	13	1	1	4	99.3
Nicotine, 5%	27	1	329	1065	0
Derris resins, 5%	25	1	558	861	0

[1] Based on examination of 30 leaves in experiment 1 and 200 leaves in experiments 2 and 3.

and small particles could be detected (Formulas 12, 13). A second treatment destroyed the newly hatched survivors, and the treated plants developed clean new foliage and fruited more abundantly than did untreated checks, which remained stunted and brown owing to continued feedings of the lacebugs. Only a few adults migrated into the treated area during the 6 weeks subsequent to treatment.

POTATO APHIDS.—Three tests with aerosols were made near Houlton, Maine, against heavy infestations of aphids on potato. Both 4-nozzle and 6-nozzle dispensers were used, with and without curtains, at a speed of 3 miles per hour.

The heavy decumbent vines of Katahdin potatoes, in which experiment 1 was made, presented a severe test of the insecticides. The applications were made August 12 as temperatures near 100° F. and a wind velocity near 3 miles per hour. The results as recorded in table 8 indicate the greatest reductions of aphids by the 5 and 10 per cent DDT aerosols in formulas 10, 11, 12, and 13 when the 4-nozzle dispenser was used with the canopy. More aphids survived when the canopy was not used on this dispenser. As might be expected, the 6-nozzle dispenser, which directs the aerosol downward, was less efficient than the 4-nozzle row machine, in which the nozzles are on the sides. The light DDT aerosols (Formulas 11 and 13) were less effective than the heavier ones (Formulas 10 and 12) indicating that the latter penetrated among the foliage and left a more toxic deposit. The differences between the heavy and light 10 per cent DDT aerosols (Formulas 12 and 13) were greater when the 6-nozzle dispenser was used. The combination of derris resins and DDT (Formula 24) appeared to be less efficient than DDT in formula 10. The nicotine aerosol stupefied the aphids, which fell to the ground within a few minutes, but many seemed to have recovered by the following day. The nicotine-copper ammino-oleate

Table 8.—Effect of aerosols on aphids on Katahdin potato. Experiment 1, Houlton, Me.

Active Ingredient	Formula	Number of Nozzles	Curtain	Number of Surviving Aphids[1]				Per Cent Reduction
				Aphis abbreviata	*Macrosiphum solanifolii*	*Myzus persicae*	All Species	
Untreated checks	—	—	—	729	173	15,285	16,187	
DDT, 5%	10	4	Yes	154	25	763	942	94.1
			No	50	39	1,027	1,116	93.1
	11	4	Yes	112	8	1,054	1,174	92.7
			No	204	51	1,476	1,731	89.3
DDT, 10%	12	4	Yes	16	8	514	538	96.7
			No	102	22	666	790	95.1
		6	Yes	81	51	2,790	2,922	81.9
			No	252	114	5,294	5,660	65.0
	13	4	Yes	166	9	745	920	94.2
			No	187	16	2,114	2,317	85.7
		6	Yes	280	46	2,999	3,325	79.4
			No	161	150	3,959	4,270	73.6
Derris resin, 5% and DDT, 5%	24	4	Yes	184	39	2,248	2,471	84.7
			No	209	15	3,338	3,562	77.9
Nicotine, 5%	26	4	Yes	1	7	1,637	1,645	89.8
		6	Yes	77	33	4,610	4,720	70.8
			No	311	37	4,303	4,651	71.3
Nicotine copper ammino-oleate, 10%	28	4	Yes	112	17	3,604	3,733	76.9

[1] Records made on 3 leaflets of top, middle, and bottom leaves of 24 plants.

gave a partial reduction of aphids.

Although showing high percentage reduction, the results in table 8 do not give a true picture of the effect on the aphids, since large numbers of dead aphids, often the entire population on a plant, were on the ground in plots treated with formulas 10, 11, 12, and 13. In the DDT treatments large proportions of the survivors were often found on a few of the large leaves in close contact with the ground or pressed down by the wheels during treatment, emphasizing the need of a vine-lifter attachment on the dispensing machine. These DDT-treated plots remained greener through the early part of September than the untreated areas or the nicotine-treated plots.

Applications in experiment 2 were made on August 14 to upright growth of Sebago potatoes with the 4-nozzle row machine. The temperature was 91° F. and the wind velocity near 12 miles per hour. Uniformly high kills of *Macrosiphum solanifolii* (Ashm.) on the terminals were obtained with both light and heavy DDT aerosols and with nicotine, but not with derris (Table 9). Lower efficiency of the lighter aerosols (Formulas 11 and 13) as compared with the heavy ones (Formulas 10 and 12) is indicated by the results with the mixed aphid population. It was of interest that *Myzus persicae* (Sulz.) on the weeds *Raphanus raphanistrum* and *Brassica* spp. growing in the same rows was little affected by the treatments immediately after application. However, the aphids disappeared from these weeds in the DDT-treated plots during the next 3 weeks. These weeds grew and flowered more luxuriantly than in the untreated areas.

The lower percentage kill of aphids in experiment 2 than in experiment 1 or 3 was apparently due to inadequate closure at the front of the applicator, which failed to reduce the wind currents through the aerosol dispenser.

Table 10.—Effect of aerosols on aphids on Sebago potato. Experiment 3, Houlton, Maine.

Active Ingredient	Formula	Surviving Aphids per Plant[1]	Per Cent Reduction
Untreated check	—	937	—
DDT, 10%	12	25	97.3
DDT, 5%	23	10.5	98.8
Nicotine, 5%	26	6.1	99.3
Nicotine plus oil, 5%	27	8.8	98.0
Nicotine copper ammino-oleate, 10%	28	44.8	95.2

[1] *Aphis abbreviata* 41.5, *Macrosiphum solanifolii* 20.8, and *Myzus persicae* 37.7 per cent.

In experiment 3, where five aerosols were applied to heavy growth of Sebago potatoes on August 17 at temperatures near 79° F. and wind velocity near 3 miles per hour, high kills of aphids were obtained with a heavy 10 per cent and a light 5 per cent DDT aerosol and with the three nicotine aerosols (Table 10). As in experiment 1, the aerosol containing nicotine-copper ammino-oleate tended to clog the nozzles during application. The need for a vine lifter on the applicator for the greatest efficiency of the aerosol was again indicated. In this field *Aphis abbreviata* Patch occurred in large numbers.

OTHER INSECTS.—In the course of these experiments observations were made on the insects on the aerosol-treated crops. Most of these species occurred in too small numbers for making definite comparisons between treatments, but the effects ob-

Table 9.—Effect of aerosols on aphids on Sebago potato. Experiment 2, Houlton, Maine.

Active Ingredient	Formula	*Macrosiphum solanifolii*		Mixed Species[1]	
		Surviving Aphids on 25 Terminals	Per Cent Reduction	Surviving Aphids	Per Cent Reduction
Untreated check	—	3802	—	3528	—
DDT, 5%	10	332	91.2	1030	70.8
	11	313	91.7	1504	57.3
DDT, 10%	12	102	97.3	319	90.9
DDT, 10%	13	25	99.3	658	81.3
Derris, 5%	25	1575	58.5	2672	24.2
Nicotine, 5%	27	290	89.7	2292	35.0

[1] *Aphis abbreviata* 5, *Macrosiphum solanifolii* 2, and *Myzus persicae* 93 per cent. Results based on 3 leaflets from upper, middle, and lower leaves from 72 plants in each treatment.

served appear worth while recording. The results are given in table 11 and the following discussion. Most of these insects were very susceptible to the DDT aerosols to which they were exposed, the only exceptions being the squash bug, the harlequin bug, and the Mexican bean beetle.

Japanese Beetle.—Edible soybeans, infested with Japanese beetles at the University of Maryland Farm, were treated on August 1 with two aerosols containing 5 and 10 per cent of DDT, also with a dust containing 5 per cent of DDT in pyrophyllite and a spray emulsion containing 1 gram of DDT, 3 grams of xylene, 1 gram of *Triton X-100* (an aralkyl polyether alcohol) in water to give a spray containing 0.4 pound of DDT per 100 gallons. As indicated in table 11, the beetles were paralyzed by all materials at the end of 12 hours, and all were dead in 3 days. The aerosols were slightly more rapid both in initial stimulation and paralytic action than were the sprays or dusts.

Squash Bugs.—After one application of 5 or 10 per cent DDT aerosol on summer squash, the bugs were irritated and ran about rapidly. The population of bugs was reduced in the plots following treatment, and a considerable number of dead young nymphs were found on the ground. Following a second treatment with 10 per cent DDT aerosol (Formula 12) only the smallest nymphs among collected individuals kept in cages died in 4 days (Table 11); the large nymphs and adults remained as active as those in check cages.

Mexican Bean Beetles.—Several aerosol formulas containing DDT and derris resins (Formulas 3, 12, 23, 24, 25, 30, and 31) were tested in three experiments against the Mexican bean beetle on snap beans. DDT aerosols in formulas 3 and 12 caused yellowing and dwarfing of the plants due to excessive cyclohexanone, since aerosols lacking cyclohexanone (Formulas 23 and 31) caused no injury. The derris resins (Formulas 24, 25, and 30) caused no injury and reduced the population of beetles. The adults and larvae were knocked down by the DDT aerosols and apparently were killed on the ground when exposed to the hot sun. However, individuals taken to the laboratory from beneath treated plants recovered by the following day. Further work is needed before these aerosols can be evaluated against the bean beetle.

EFFECT ON INSECT PREDATORS.—No careful study has been made of the effect of DDT aerosols on insect predators and parasites. However, adults and larvae of coccinellids were collected from peas in somewhat fewer numbers after treatment with DDT aerosols than before the applications. Syrphid larvae appeared to be little affected by treatments with DDT aerosols (Table 5). No living aphis lion

Table 11.—Effect of DDT aerosols on miscellaneous insects on vegetable crops.

AEROSOLS USED				
Per Cent DDT	Formula	SPECIES	CROP TREATED	EFFECT ON INSECT
5, 10	10, 12	Colorado potato beetle	Potato, tomato, eggplant, *Solanum carolinense*	Adults and larvae paralyzed, dead in 24 hours.
		Japanese beetle	Soybean	Adults paralyzed in 12 hours, dead in 3 days.
	3, 4	Phyllophaga	Peas	Adults dead in 24 hours.
	10, 12	Spotted cucumber beetle	Squash	Adults paralyzed, dead in 24 hours.
		Striped cucumber beetle	Squash, cantaloupe	
10	12	Cabbage looper	Kale, lettuce	Larvae paralyzed, dead in 24 hours.
		Imported cabbage worm	Kale	
		Tomato hornworm	Tomato	Half-grown larvae killed.
5, 10	10, 12	Clover leafhopper	Lettuce, potato	Adults and nymphs killed.
		Potato leafhopper	Beans, lettuce	
		Thamnotettix nigrifrons Forbes	Lettuce	
10	12	Harlequin bug	Kale	Adults killed in 2 days, nymphs survived.
		Squash bug[1]	Squash	Only small nymphs died.
5, 10	3, 4	Seed-corn maggot	Peas	Adults dead in 12 hours.

[1] 5 per cent nicotine (formula 27) and 5 per cent derris resin (formula 25) produced no mortality on squash.

(Chrysopidae) larvae were collected immediately after treatment, but a week later they were swept from treated plots. It appeared that the DDT aerosols had only a temporary effect at most on the field populations of these insect predators. The effects were quite different, however, on populations of carabid beetles, which were susceptible to DDT aerosols. In fields of peas, potatoes, lettuce, and beans many dead adults and no living ones were found after 24 hours. Among collections of adults killed by aerosols containing 5 or 10 per cent of DDT (Formulas 10, 12), J. M. Valentine recognized the following species: *Dicaelus dilatatus* (Say), *Harpalus pennsylvanicus* (Deg.), *H. compar* (Lec.), and *H. faunus* (Say).

DISCUSSION.—The aerosols containing DDT appeared to be more efficient against a number of pests on vegetables than those containing derris or nicotine. They were also more effective than insecticides generally recommended against several pests, including the aster leafhopper, the onion thrips, the eggplant lacebug, and the garden webworm. The residual effect of DDT against such disease vectors as the aster leafhopper may prolong the period of protection against spread of virus diseases.

In the experiments on potato the need was demonstrated for a curtain, or canopy to confine the aerosol until it became distributed among the foliage. The need for a vine lifter on heavy growth of potatoes seemed evident, since most of the surviving aphids were found on the leaves in close contact with the ground. With very susceptible insects there is probably no need for a canopy except in windy weather.

SUMMARY.—The toxicity of DDT aerosols was observed in field treatments on 31 species of insects attacking vegetable crops or predators on these insects. Many of the plant pests, including the onion thrips, the potato flea beetle, the tarnished plant bug, the spittle bug, the aster leafhopper, the garden webworm, the eggplant lacebug, the potato aphid, and lepidopterous larvae were found susceptible. Among the resistant species were the harlequin cabbage bug, the squash bug, the Mexican bean beetle, coccinellid adults and larvae, and syrphid larvae.

The aerosols containing nicotine generally gave lower kills or were ineffective, while most of those containing derris resins were ineffective.

The heavy DDT aerosols, producing larger droplets, were generally more effective than the lighter aerosols. Against most insects aerosols containing 5 per cent of DDT, when efficiently applied, were practically as effective as those containing 10 per cent of DDT. A canopy on the applicator to allow for distribution of the aerosol and prevent wind drift increased efficiency of the treatment in most cases. No plant injury occurred except on lima beans and snap beans treated with DDT aerosols containing high proportions of cyclohexanone.—1-9-45.

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SWEETPOTATO WEEVIL QUARANTINES

Part of Liberty County, Fla., was added to the area designated as infested with sweetpotato weevil in a revision of February 12, 1945, of the State Plant Board's Rule 7. The Georgia State Plant Board's Quarantine No. 3, revised February 1, 1945, added part of McIntosh County, Ga., and all of Escambia and Liberty Counties, Fla., to the regulated area.

DDT to Control Corn Flea Beetle on Sweet Corn and Potato Leafhopper on Alfalfa and Peanuts

F. W. Poos, *U.S.D.A., Agr. Res. Adm., Bureau of Entomology and Plant Quarantine*

Preliminary small-scale field tests of DDT for the control of the corn flea beetle, *Chaetocnema pulicaria* Melsh., on sweet corn, and the potato leafhopper, *Empoasca fabae* (Harr.), on alfalfa and peanuts, were conducted during 1944.[1] Although the results of these tests were favorable, further information is needed on the best DDT mixtures, dosages, and treatment schedules, and on any residue hazards that may result from the use of DDT on the crops tested. No injury to the foliage of any of these crops was apparent when treated with the various formulas containing DDT as reported herein.

Corn Flea Beetle.—The purpose of this experiment was to find an insecticide effective against the corn flea beetle in Victory gardens where this insect is frequently destructive to stands of sweet corn in the seedling stage. More often it is important as a vector of the destructive bacterial wilt or Stewart's disease of sweet corn. On May 3 a small planting was made of two varieties of sweet corn, one susceptible to bacterial wilt and one resistant. A moderate population of adult beetles was present on this planting, as well as on two short rows of very early sweet corn in a Victory garden nearby. In each variety alternate rows were sprayed by means of a knapsack sprayer with 0.66 per cent DDT on May 13, 16, 22, 23, and 29. The adjacent rows were left unsprayed. The spray mixture consisted of 252 grams of 10 per cent DDT in pyrophyllite added to 1 gallon of water containing one and one-half teaspoonfuls of a proprietary spreader (sodium oleyl sulfate with a synthetic resinous sticker). As shown in table 1, the maximum number of beetles found per 100 untreated plants was 151, whereas only 2 adults per 100 plants were found on an adjacent treated row.

The corn plants in the treated rows were larger and more numerous than those in the untreated rows. This difference was especially pronounced in the susceptible variety, where the treated rows contained 75 per cent more plants than the untreated rows on July 7, although it was also evident in the resistant variety. This suggests the possibility that the resistant variety is dwarfed by the wilt even though the usual external symptoms are not present.

Damage caused by drought, crows, and wilt prevented data on yields of roasting ears being obtained from the wilt-susceptible variety. In the resistant variety the untreated rows yielded 79 ears and the treated rows 93, or an increase of 17.7 per cent; there was no significant difference in the stand.

Although a practical dosage and schedule of treatments were not determined, this experiment indicates that the corn flea beetle, and to a certain extent the bacterial wilt, can be controlled in early sweet corn by the use of a DDT spray.

Potato Leafhopper on Alfalfa.—Owing to an early season, the first two cuttings of alfalfa were made earlier than usual. A moderate infestation of the potato leafhopper developed on the third crop, which grew more slowly than normally because of drought conditions. On July 26 and August 4 three small areas (each 2 by 3 rods) were treated with a 0.66 per cent DDT spray (same formula as applied for the corn flea beetle), a 2 per cent DDT dust in pyrophyllite, and a

Table 1.—Effect of DDT on populations of the corn flea beetle on sweet corn. Beltsville, Md., 1944.

Type of Sweet Corn and Date of Beetle Counts	Beetles per 100 Plants	
	Treated	Untreated
Victory garden (very early)		
May 18	1	19
29	1	49
30	1	81
31	1	64
Wilt-susceptible		
May 30	1	139
31	3	94
June 9	2	21
Wilt-resistant		
May 31	2	151
June 9	1	52

[1] The experiments on corn and alfalfa were carried out at Beltsville, Md., and those on peanuts were made at Holland, Va., in cooperation with E. T. Batten, of the Virginia Agricultural Experiment Station.

pyrethrum-sulfur dust containing 0.1 per cent of pyrethrins. The spray material was applied at the rate of approximately 27 gallons and the dusts at approximately 25 pounds per acre-application. Population counts made at various intervals following the treatments are given in table 2. They show that good control of the potato leafhopper was obtained with all three insecticides. Of most interest, however, is the fact that no nymphs of the potato leafhopper developed in the areas where DDT was applied, whereas the pyrethrum-sulfur soon lost its effectiveness and nymphs began developing within a comparatively short time after this material had been applied.

Table 2.—Population counts[1] of the potato leafhoper on alfalfa treated with DDT or a pyrethrum-sulfur dust. Beltsville, Md., 1944.

	Adults							Nymphs						
	July		August					July		August				
Treatment[2]	26	27	1	4	5	11	28	26	27	1	4	5	11	28
DDT:														
Spray, 0.66% plus proprietary spreader	—	15	16	14	2	2	9	—	3	0	0	0	0	0
Dust, 2% in pyrophyllite	—	2	18	15	4	8	16	—	1	0	0	0	0	0
Pyrethrum sulfur dust (0.1% pyrethrins)	—	3	30	21	2	2	36	—	0	9	11	0	0	10
Check (untreated)	38	28	114	110	74	81	125	33	32	39	59	39	50	88

[1] Collections based on 25 strokes of an insect net 15 inches in diameter.
[2] All treatments applied on July 26 and again on August 4.

The first of two sets of yield samples was taken on August 11, at which time the alfalfa was ready for harvest. Three samples, each 1 square yard in area, were cut from each treated plot, and six samples were similarly cut from the untreated areas nearby. There was no significant difference in the unit weight of air-dried hay obtained from the treated as compared with the untreated areas, but the treated alfalfa was green whereas the untreated was turning yellow because of leafhopper attack. This field was not harvested as expected, and on August 29, by which time the untreated plots had become very yellow, yield samples were again taken. On the basis of these samples the weight of air-dried hay per square yard from the DDT-sprayed plot war 10.5 per cent greater, from the DDT-dusted plot 12.2 per cent greater, and from the pyrethrum-sulfur dusted plot 7.1 per cent greater than the yield from the untreated areas. Probably more important was the fact that the hay obtained from the treated plots was at least one full grade better than that from the untreated plots. The results of this preliminary test indicate that mixtures containing low concentrations of DDT will effectively control the potato leafhopper on alfalfa.

Potato Leafhopper on Peanuts.—In addition to a comparison of six schedules to determine the best time for applying sulfur dust and the number of applica-

Table 3.—Average number of potato leafhoppers in 4 to 11 collections[1] on peanut foliage treated with DDT or a sulfur dust, Holland, Va., 1944.

	Adults					Nymphs				
	July			August		July			August	
Treatment[2]	13	20	29	9	17	13	20	29	9	17
DDT, 2% inpyrophyllite	—	—	4.0	3.0	0.8	—	—	0.3	0.5	0.3
Sulfur dust	1.3	1.8	7.5	2.5	4.8	2.0	6.0	1.0	1.5	10.3
Check (untreated)	4.8	12.6	20.0	9.1	15.1	6.5	11.2	5.7	7.4	15.8

[1] Collections based on 25 strokes of an insect net 15 inches in diameter.
[2] DDT applied on July 20 and August 5, sulfur on July 6 and 20 and August 5 and 17.

tions necessary to control the potato leafhopper and *Cercospora* leaf spot on peanuts, one test was made with DDT dust (2 per cent in pyrophyllite) on a field basis, each schedule being tested on two 16-row stack rows of peanuts extending across the entire field. Each application was at the rate of approximately 20 pounds of dust per acre. Yield data obtained from these plots were contradictory owing to irregularities in fertility that were not evident until the peanuts were dug, and are therefore not presented. Only moderate leafhopper populations were present on these plots during July, and heavy rains submerged the entire field on the night of August 1. Leafhopper population counts on treated plots are shown in table 3.

It may be noted from table 3 that two applications of a 2 per cent DDT dust were more effective in controlling the potato leafhopper on peanuts on a field basis than were four applications of sulfur dust. Of most significance in the tests against the potato leafhopper was the residual effect of the DDT, which seemed to prevent nymphal development of this leafhopper almost entirely on the alfalfa and peanut foliage treated with this insecticide.

DDT as an Automatic Killing Agent in Japanese Beetle Traps

GEORGE S. LANGFORD, MARTIN H. MUMA and E. N. CORY, *University of Maryland, College Park*

Traps are being used extensively in Maryland as an aid to Japanese beetle control. Since 1938 between 50,000 and 100,000 traps have been employed each year. The standard trap now used must be visited periodically to remove beetles from the trap container. This operation is time consuming and can become quite expensive. At best, disposal of the trapped beetles is a problem.

Research at the University of Maryland for the past several years has had as its objective the development of a trap that would not need emptying. To this end several traps through which beetles may pass after having been exposed to an insecticide have been designed and tested. These traps achieved limited success using such insecticides as pyrethrum, rotenone and oils. With the discovery of the insecticidal value of DDT for killing Japanese beetles research on its usefulness as an automatic killing agent in traps was initiated. The results obtained were highly successful.

THE TRAP.—In the past season several traps were designed and tested using DDT as a killing agent. In the traps used the beetles were allowed to fall through a funnel, strike a surface coated with the insecticide and fall free. Basically, the trapping function remained the same as that of the standard trap. Beetles were attracted by a bait situated in the baffles and after striking the baffles fell through a steep-sided funnel.

In addition to the standard type trap three designs of traps were built and tested; one type was square having all

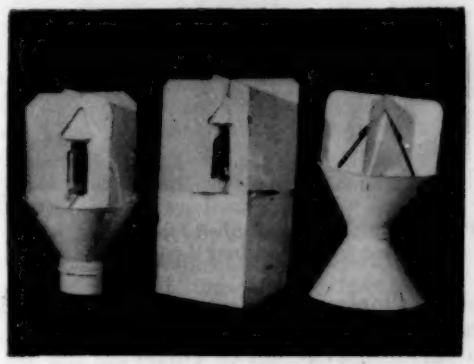

FIG. 1.—Three traps designed to test the value of DDT as an automatic killing agent.

parts modified into troughs and roofs; the other types were round, differing in size of funnel opening and complexity of the rain protecting apparatus. The three designs are shown assembled in figure 1. The apparatus containing DDT was suspended below the opening of the funnel replacing

the beetle container used in the standard trap. Anticipating a reduction in efficiency of the poison due to weathering, rain protection was provided. This protection consisted simply of a deflecting cone set in the baffles above the opening of the funnel, a perforated trough or gutter on the inside of the funnel and a fender on the outside to divert the water away from the trap.

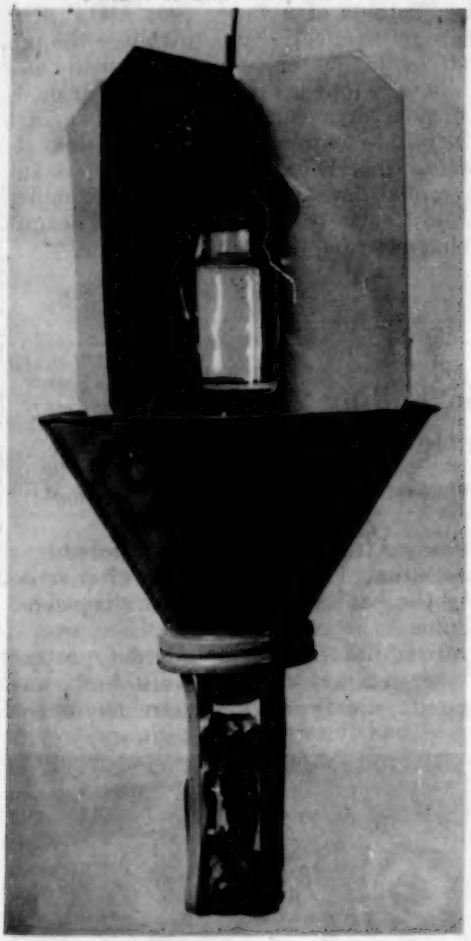

FIG. 2.—Bait bottle, modified for use as a poison dispenser, fixed below funnel opening of trap.

Various types of insecticide or poison dispensers were used. Early in the study it was found that DDT could be used either in liquid or solid media. Small cans or bait bottles equipped with wicks were used for the liquids and small cups or open salve boxes for the solids. Killing surfaces ranging in diameter from 1 to 2 inches were tested. The containers with the killing agent were suspended approximately 0.75 of an inch below the funnel opening in metal baskets or wire clips. Figures 2 and 3 show the arrangement of dispensers for liquids and solids respectively.

All traps showed a high degree of efficiency. A modified standard trap is probably all that is necessary. Containers with solid media gave satisfactory performance without rain protection.

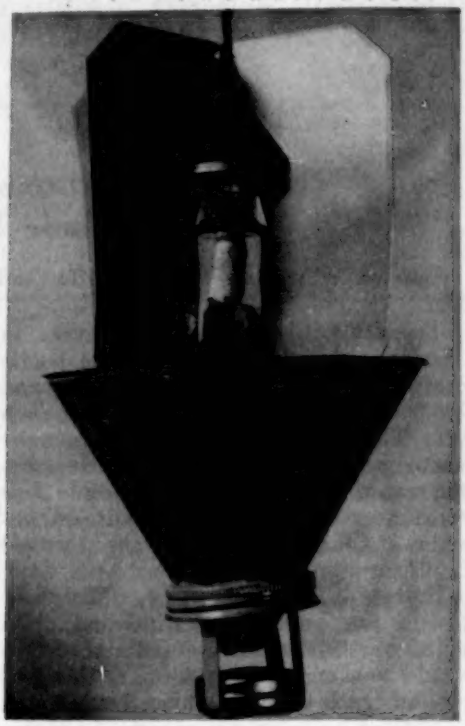

FIG. 3.—Salve box, used for dispensing poisons in solid media, fixed below funnel opening of trap.

THE POISON.—Tests throughout the season indicated that DDT could be used in liquid or solid media. Solid media tested included mixtures of DDT with palmitic acid, lard, vaseline, axle grease and bearing grease (*Mobile Grease no. 5*). Only one liquid medium was used. It was composed of one part each of light white mineral oil (Saybolt viscosity 125–135), *Deobase* oil, and a saturated solution of xylene and DDT.

Solid media mixtures were of two types, one containing pure DDT and one a 20

Table 1.—Comparative data for several effective killing mixtures of DDT.

MIXTURE OF DDT	TYPE AND SIZE KILLING SURFACE	NO. READINGS	TOTAL CATCH	PER CENT MORTALITY		
				Min.	Max.	Av.
Straight DDT—1 part Axle Grease—3 parts	2.25″ Salve Box	18	1757	83	100	98
Same	1.25″ Salve Box	18	1241	100	100	100
Same	1″ Salve Box	11	997	97	100	99
Check	None	18	601	0	83	42
DDT in Xylene—1 part Bearing Grease—2 parts[1] Pyrophyllite—4 parts	1″ Salve Box	21	1558	50	100	86
Check	None	14	902	0	42	22
DDT in Xylene—1 part *Deobase* Oil—1 part Mineral Oil—1 part	Oil Can 2.25″ Cotton Pad	23	6407	97	100	99
Same	Oil Can 1.25″ Cotton Pad	18	1155	84	100	98
Same	Bait Bottle 1″ Wick	29	2179	80	100	98
Check	None	29	2650	0	63	33

[1] The bearing grease used in the study was *Mobile Grease No. 5*.

per cent DDT in pyrophyllite. Most of the mixtures were efficient when compounded to a consistency that would support the weight of a beetle. Tests indicated that axle grease was one of the cheapest and best when mixed in the proportion of 3 to 1 with pure DDT and used in an open cup or salve box about an inch in diameter.

The oil mixture proved effective in any of the sizes and types of containers used. After 10 days a crystalline crust of DDT that did not appear to affect the lethal quality was noted on the wicks and pads. Modified bait bottles having a pad or cotton wick about one inch in diameter for dispensing the DDT proved as efficient as any of the other containers.

METHODS.—All observations were made under field conditions. The traps were placed in linear batteries, each type of trap and killing mixture being replicated two or three times. Beetles passing through the traps were retained in screen cages or in beetle containers from standard traps. Containers used with DDT traps were soaked in kerosene, washed with strong laundry soap, rinsed thoroughly and aired between each reading.

RESULTS.—Data collected indicate that DDT used in either liquid or solid media is an effective killing agent for the automatic trap. Table 1 gives comparable results for some of the more efficient mixtures. Data for each reading is based on the total number of beetles passing through a trap in a period of approximately 12 hours.

As a solid medium, axle grease mixed with DDT in the ratio of 3 to 1 and exposed in salve tins makes an effective killing agent. An exposed surface from one to one and one quarter inches in diameter is satisfactory for kill and will permit beetles to fall free of the trap. Consistent kills of 100 per cent were obtained in several tests. In some instances low mortality was noted, however, in every case this reduction could be traced to an improperly adjusted killing surface.

A satisfactory liquid medium may be prepared by mixing a saturated solution of xylene and DDT, one part, with one part each of deobase oil and light white mineral oil. A modified bait bottle equipped with a wick arranged to provide a contacting surface of approximately one inch diameter was efficient in dispensing the liquid and killing beetles. With this equipment the average kill for 18 observations was 98.4 per cent.

DDT to Control Japanese Beetles on Fruit

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Throughout the past summer DDT was tested on peach, apple, plum, cherry, and grape, to determine its effectiveness for the protection of both fruit and foliage from injury by the Japanese beetle. The comparative efficiency of the material in water suspension and in emulsion with ethylene dichloride as the solvent was tested. Such factors as toxicity, plant injury, repellency, compatibility with the fungicides sulphur and bordeaux mixture and kill from residues was given consideration. The influence of the addition of certain wetting agents and stickers as well as the coarseness or fineness of spray was also noted.

Results of the work show DDT to be effective for Japanese beetle control. The relative degree of effectiveness is dependent upon whether it is used as a suspension or an emulsion and upon such factors as rainfall, plant growth, and abundance of beetles. It possesses a combination of properties not exhibited by other insecticides now utilized for Japanese beetle control. It has good repellent qualities and is decidedly toxic as a contact spray. The dried residue on foliage is quite lethal.

It was found to be efficient in the difficult task of protecting early ripening peaches, apples and plums. In water suspension it appeared to be compatible with sulphur, bordeaux mixture and lime sulphur, and was non-injurious to plants upon which those fungicides can be used with safety. Ethylene dichloride emulsion appeared to be compatible with bordeaux mixture.

On the basis of toxicity of dried residue on foliage, the water suspension applied as a coarse spray without the addition of a wetting agent was more effective than the emulsion. The emulsion was more desirable on ripening fruit as it left no obvious residues.

MATERIALS USED.—In studying the toxicity of DDT to the Japanese beetle xylene and ethylene dichloride emulsions and water suspensions of 20 per cent DDT in pyrophyllite were used as sprays and 2.5, 5, and 10 per cent DDT in pyrophyllite were used as dusts. The water suspension as a spray was tested with rosin residue emulsion (*Nu Film*) as a sticker and in combination with the fungicides bordeaux mixture, sulphur and lime sulphur. In addition, the water suspension was tested with sodium lauryl sulphate as a wetting agent. Both compressed air and power sprayers were used. Most of the field work was done with power sprayers at pressures varying from 300 to 600 pounds. The dusts were all applied with a rotary-type hand duster.

All emulsions used in these experiments were prepared by dissolving 20 parts, by weight, of DDT in either xylene, or ethylene dichloride, and adding 20 parts, by weight, of *Triton N.E. 100*. Water suspensions were made by adding 20 per cent DDT in pyrophyllite directly to water. Dosages expressed as 1 pound of DDT to 100 pounds of spray indicate that 1 pound of actual DDT, by weight, is contained in 100 gallons of water or spray mixture.

Preliminary work indicated that the xylene emulsion was injurious to plant foliage when used in combination with bordeaux mixture or applied to foliage coated with sulphur. Therefore, this emulsion was not used in any of the large scale tests.

TOXICITY.—No effort was made to determine the minimum effective dosage for DDT against the Japanese beetle. Sprays carrying a minimum of 4 ounces of DDT to 100 gallons in emulsions or water suspension killed 100 per cent of the beetles when they were exposed to direct wetting for thirty seconds in a wire cage, dried on blotting paper and held in clean cages. Results obtained from field spraying were not quite so efficient since spraying usually disturbed the beetles and large numbers flew away to avoid the spray. The mortality among such disturbed beetles was not recorded. Beetles collected from sprayed grapes and caged immediately following the spraying had some recovery. In most tests 100 per cent mortality was recorded, but in some collections recovery to the extent of 10 per cent was noted. A 2.5 per cent dust was effective in killing all beetles thoroughly dusted.

Beetles sprayed or dusted with DDT usually began to show definite reaction within five minutes. Within 30 minutes to 1 hour most beetles were down and on

Table 1.—Results obtained by exposing Japanese beetles for 30 seconds on foliage collected at random from plants sprayed with mixtures containing 1 pound of DDT to 100 gallons of spray. All residues exposed to weathering for periods ranging from 1 to 24 days. All tests were run with checks and no observation is recorded in which check showed mortality.

Spray	Age of Residue in Days After Spraying								
	1	2	3	4	7	14	18	20	24
	Percentage of Beetles Down after 24 Hours								
	Apple								
20% DDT-Pyrophyllite in water suspension	100.0	100.0	100.0	96.6		50.0	69.9	30	24
20% DDT with Rosin Residue Emulsion			100.0	86.6	13.3				16.6
20% DDT in 4-8-50 Bordeaux	96.6	73.2				50.0			
20% DDT with Sodium Lauryl Sulphate		56.6				26.6	63.2		
Ethylene Dichloride (DDT) emulsion		13.3		0.0	16.5	3.3			0.0
Ethylene Dichloride (DDT) emulsion with Rosin Residue			3.3	0.0	9.9				0.0
	Grape								
20% DDT-Pyrophyllite in water suspension	100.0	100.0		76.6	100.0	23.3			40.0
20% DDT with Rosin Residue Emulsion			50.0	100.0		6.6			
20% DDT in 4-8-50 Bordeaux mixture	100.0	100.0		86.6	93.3	20.0			
20% DDT with Sodium Lauryl Sulphate		100.0		16.6	63.3	6.6			
Ethylene Dichloride (DDT) emulsion	26.6			10.0	20.0	0.0	20.0		
Ethylene Dichloride (DDT emulsion and Rosin Residue			13.3	0.0					
	Peach								
20% DDT Pyrophyllite in water suspension				53.3	83.3	6.6			
20% DDT with Sodium Lauryl Sulphate				13.3	70.0	0.0			
Ethylene Dichloride (DDT) emulsion					43.3				

their backs. Death usually occurred within 24 hours though some lingered as long as 48 hours.

TOXICITY OF DRIED RESIDUES.—Dried residues of DDT on foliage were decidedly toxic to a large percentage of the Japanese beetles contacting it. This toxicity was noted under field conditions by observing beetles that visited sprayed foliage. Not uncommonly beetles were overcome and died upon, and in the axils of sprayed grape leaves. Dying beetles were seen near and under treated foliage for days after spraying.

The toxicity of dried residues in these studies was determined by removing leaves at random from sprayed plants and exposing beetles upon them. For each test 90 beetles were exposed, 30 each for periods of 30 seconds, 1 minute, and 5 minutes. Recordings were made on the total number of beetles down or dead at intervals of 15 minutes, 30 minutes, 1, 2, 4, 6 and 24 hours.

In general the rate at which the beetles were overcome followed the period of time they were exposed to the residue. Beetles exposed for 5 minutes reacted somewhat

Table 2.—Results from exposing Japanese beetles for 30 seconds to dry DDT residues obtained by evaporating 1 c.c. of spray mixture in the bottom of 2 inch flat bottomed dishes.

Pounds DDT in 100 Gal.	Mixture	Per Cent of Beetles Down				
		15 min.	30 min.	1 hr.	2 hrs.	Check
2 lbs.	20% DDT in Pyrophyllite water suspension	26.6	19.9	93.3	93.3	0
	Ethylene dichloride emulsion	16.6	30.0	40.0	33.3	0
1 lb.	20% DDT in Pyrophyllite water suspension	46.6	93.3	97.6	100.0	0
	Ethylene dichloride emulsion	3.3	0.0	3.3	10.6	0
0.5 lb.	20% DDT in Pyrophyllite water suspension	36.6	76.6	100.0	93.3	0
	Ethylene dichloride emulsion	0.0	3.3	3.3	3.3	0
0.25 lb.	20% DDT in Pyrophyllite water suspension	52.8	73.3	93.3	96.6	0
	Ethylene dichloride emulsion	6.6	6.6	3.3	6.6	0

faster than those exposed for only 30 seconds, but a 30 seconds exposure was sufficient for kill. Table 1 shows the results obtained for residues containing DDT that had weathered for periods ranging from one to twenty-four days. A water suspension of 20 per cent DDT in pyrophyllite gave the most efficient and lasting residue. While some kill was obtained from the residue deposited by the ethylene dichloride emulsion its efficiency was much less than that obtained by the water suspension. Originally this difference was thought to be due to run-off and the probabilities are that a large proportion was due to that factor. But preliminary tests in which beetles were exposed to residues left by evaporating equal volumes of spray mixture one from emulsion and one from water suspension showed that reaction from the water suspension was the more rapid. This would indicate that some other factor or factors are involved. Sample results are given in table 2.

In field work the use of rosin residue emulsion did not appear to improve kill from residues deposited by either the water suspension or emulsion. Neither did the addition of sodium lauryl sulphate to the water suspension give improved kill over the plain suspension.

PROTECTION OF FRUIT AND FOLIAGE.—Fruit or foliage coated with spray residues containing DDT was repellent to Japanese beetles. DDT dust coated foliage was also repellent, but no comparative tests were made to determine the lasting qualities of dusts as compared with sprays.

Results obtained through the season indicated that the period of protection through repellency varied. Excellent protection was obtained for periods ranging from 7 to 14 days. In a few instances protection was had for longer periods. Sufficient data were not collected to isolate with exactness, the influence on repellency of such factors as host preference, rainfall, plant growth and abundance of beetles, but general observations indicated they were important. Rate of growth was a major factor. In the case of grapes and fast growing nursery stock such as plum, cherry and apple, beetles on occasions returned and destroyed the new growth without feeding on sprayed foliage.

In comparative tests the water suspension gave on the average, longer periods of protection than ethylene dichloride emulsion. The addition of rosin residue emulsion to the sprays as a sticker did not appear to prolong the periods of protection. No improvement was observed by the use of sodium lauryl sulphate as a dispersing agent in the water suspension. Most prolonged protection was obtained with water suspensions applied as a coarse spray.

Six tests on grape foliage showed protection ranging from 11 to 20 days. The variety susceptibility to Japanese beetle attack and the rate of growth were important factors. In general at least 75 per cent control of foliage damage may be expected by one spray on some varieties, though other varieties may require two sprays.

Fourteen tests on ripening peaches showed better results from the water suspension than from emulsions though the latter is preferred by many growers. In most cases an application made 8 to 10 days before ripening carried the fruit through harvest without damage from beetles, while the fruit on the check trees was completely destroyed. Likewise four tests on ripening plums gave protection up to 15 days.

In four heavily infested apple orchards the swarms of beetles in the orchards were largely destroyed and the ripening fruit and the foliage protected for the balance of the season by one application.—12-21-44.

STANDARD PEACH QUARANTINES REVISED

Phony peach quarantines of Alabama, Georgia, Missouri, South Carolina, and Texas and peach mosaic quarantines of Arizona and Texas, as revised in the winter of 1944 and 1945, are uniform and standard as to the areas against which these regulations are placed.

DDT Insecticides Developed for Use by the Armed Forces[1]

E. F. KNIPLING,[2] *U.S.D.A., Agr. Res. Adm., Bureau of Entomology and Plant Quarantine*

The need for research on the control of certain insects and arachnids affecting the health of members of the armed forces, as well as of civilians, in the present global conflict was mentioned briefly in a recent paper by Knipling & Dove (1944). Diseases transmitted by insects have been deciding factors in the outcome of military campaigns in the past. The importance of these parasites of man in the present war has been discussed by McCoy (1944). The actual menace of certain insects and insect-borne diseases to the successful outcome of the present war was anticipated, even before the outbreak of hostilities, by military and civilian medical authorities, who approached the Bureau of Entomology and Plant Quarantine with the request that it conduct investigations to develop or improve methods of combating certain of these insects.

On recommendation of the Committee on Medical Research of the National Research Council, funds for these studies were made available by the Office of Emergency Management and were transferred to the Bureau from the Office of Scientific Research and Development in 1942. The investigations were undertaken by the Division of Insects Affecting Man and Animals, and a research laboratory was established at Orlando, Fla. The original purpose of these studies was to develop control measures for the body louse and other lice affecting man; to investigate insect repellents for mosquitoes, mites, ticks, and other insects; and to develop more effective mosquito larvicides. Because of the need for substitutes for pyrethrum and rotenone, the scope of the work was later broadened to include research on insecticides for the control of adult mosquitoes, flies, bedbugs, cockroaches, fleas, ticks, and other insects of medical importance.

During the course of research on the various projects, hundreds of materials from numerous sources have been tested and evaluated as repellents and insecticides. Among these materials 2,2-bis(*p*-chlorophenyl)-1,1,1-trichloroethane, a synthetic compound first used as an insecticide in Switzerland and known in this country as DDT, has proved outstanding, and extensive investigations have been carried out on this material. This paper and others to follow in this issue deal only with results of investigations of this compound.

The original samples of DDT were a 5 per cent dust marketed under the name of *Gesarol Spray Insecticide* and a 3 per cent dust sold as *Gesarol Dust Insecticide*. These products, supplied by the Geigy Company, Inc., of New York, were given to the Division of Insecticide Investigations of the Bureau of Entomology and Plant Quarantine with information that the firm J. R. Geigy, S. A., of Basle, Switzerland, had found them to be effective agricultural insecticides.

Samples of these products were sent to the Orlando laboratory by the Division of Insecticide Investigations in November 1942. The material was first tested against the body louse and was found to be very toxic and remarkably stable, a combination of characteristics generally uncommon to the synthetics previously tested. The Geigy Company later advised that Swiss investigators had also found the material to be an effective lousicide, and that a product called *Neocid* was being marketed in the form of a powder containing 5 per cent of active ingredient.

Early in the investigations the identity of this material was not known, and the pure compound was not available. Because of the effectiveness of *Gesarol* against the body louse, the active ingredient was extracted from the original product by the Orlando chemists, and tests were made with the extract against other insects. The active ingredient was later identified and the compound was synthesized by H. L. Haller, of the Division of Insecticide Investigations, and shown to be identical with the pure product made in Switzerland.

Preliminary laboratory tests indicated that the material was not only effective against lice, but very promising against

[1] This work was conducted under a transfer of funds, recommended by the Committee on Medical Research, from the Office of Scientific Research and Development to the Bureau of Entomology and Plant Quarantine.

[2] The writer and other members of the Orlando laboratory staff are grateful for the wholehearted cooperation and assistance given by W. E. Dove, in charge of the Division of Insects Affecting Man and Animals, and by H. H. Stage, assistant Division leader.

mosquitoes, houseflies, bedbugs, fleas, and cockroaches, which fully confirmed the fact established by Swiss workers that DDT is a very effective insecticide. Prior to our entry into the war pyrethrum was used to a great extent in the control of these insects, but available supplies of pyrethrum were soon allocated for use overseas against mosquitoes and lice and it was necessary to find substitutes for use against these other insects. Intensive studies were therefore made to explore fully the possibilities of DDT in order that recommendations for its use might be made to the armed forces.

A detailed report on the results obtained with DDT against most of these insects was made at an insecticide and insect-repellent conference of the Office of Scientific Research and Development as early as May 1943. The research with this material at the Orlando laboratory had then progressed to the point that a louse powder containing it was recommended to the armed forces. However, since little was known about the toxicity to man of DDT when used in other ways against other insects, recommendations for more general use in the control of adult mosquitoes, flies, and bedbugs were withheld pending further physiological tests by toxicologists.

In view of the value of DDT in the war effort and because of the many requests for information on its practicability and methods of application for the control of certain insects affecting the armed forces, it has seemed desirable to publish some of the data on those phases of the work that can be released at this time. Although extensive tests had been conducted, results obtained with this material against certain insects were reported only briefly in the February 1944 issue of this journal, together with a large number of notes on its effectiveness as found by other workers in the Bureau (Annand *et al.* 1944). More detailed reports on some of the experimental work done by various investigators at the Orlando laboratory are presented in this issue, including results of various studies against mosquitoes.

The information gained by the intensive and coordinated research at the Orlando laboratory has already proved of great value to our forces and allies, both military and civilian, as evidenced by the success of the typhus-control program carried out last winter by the military authorities in Italy. DDT is now being made available for mosquito control. The material promises to be the greatest single weapon for the control of malaria yet developed. Its use as a residual type treatment provides a means of attack for the control of malaria mosquitoes which has not been employed prior to this time. Its use as a residual deposit against flies and other insects will also prove of great value during this war and for civilian use later.

Although rapid progress has been made in the development of DDT treatments, there is much to be done to find the best methods of application and dosages in practical use against those species already investigated, and not enough is known concerning the effectiveness of the material against many related species in different parts of the world. It is hoped that the information on DDT presented by the various investigators will stimulate further research and observations.

Materials that show promise as repellents and insecticides in tests at the Orlando laboratory are sent to various agencies and individuals for further evaluation, particularly with regard to their possible practical application. During the investigations on DDT the assistance and cooperation of many agencies and individuals have been obtained, for which we desire to express appreciation. The Offices of the Surgeon Generals of the Army and Navy have freely given information and suggestions that have been helpful in the conduct of the studies. DDT has been furnished various camps for practical tests, and personnel of the Army and Navy bases have carried out practical field tests which have provided valuable information. We are especially grateful for the cooperation of Lt. Col. J. Q. A. Daniels and other officers of the Army Air Forces Tactical Center at Orlando, Fla.

The Division of Insecticide Investigations and other divisions of the Bureau of Entomology and Plant Quarantine have furnished valuable technical advice and assistance. Various toxicologists in the U. S. Food and Drug Administration and the U. S. Public Health Service have made extensive studies on the toxicology of DDT, which is an essential phase in the development of insecticides and repellents for the armed forces. The Rockefeller

Foundation for Medical Research has cooperated and assisted in these investigations, and has carried the basic studies into the field, especially those in connection with louse control.

The Geigy Company, of New York, which supplied the original test sample, has been very generous in providing the laboratory with adequate DDT to carry out the investigations.

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DDT Insecticidal Preparations[1]

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The chemical work at the Orlando, Fla., laboratory of the Bureau of Entomology and Plant Quarantine has been directed toward the preparation of insecticidal materials in suitable form for use against insects affecting the armed forces. Some of the preparations made in the course of the investigations on DDT (1-trichloro-2,2-bis(*p*-chlorophenyl) ethane) are described in this article. Some of them have been used only experimentally, whereas others have been recommended for special uses. It should be borne in mind that these preparations were designed primarily for wartime use. For the many peacetime civilian uses other types of formulations will be required.

Because of high toxicity to many insects affecting man and because it is a stable organic compound, soluble in many solvents, DDT is extremely versatile in its use and may be prepared in a number of different ways. For convenience insecticidal preparations of DDT can be classified as dusts, solutions, emulsions, and suspensions.

DUSTS.—Commercial DDT has been difficult to grind because of its low melting point. Much of the early work on dusts at this laboratory was done with a specially prepared sample of micronized DDT (6 microns surface mean diameter by air permeation). Micronizing the undiluted material, however, is not commercially feasible. Recently one of the producers furnished several milled samples ranging in surface mean diameter from 14 to 26 microns, and there is some promise that a DDT in this size range or smaller may be prepared on a commercial scale. If this will not lump on shipping, it would be satisfactory for mixing with diluent in the field. For laboratory use DDT was ground in a hammer mill, but even with care to feed the mill very slowly considerable melting took place.

DDT may be readily ground with an inert diluent, however, and a large number of such dusts have been prepared at this laboratory in a hammer mill. A mixture of equal parts of DDT and talc, for example, was ground to 3.0 microns in one passage through the mill, although care was necessary to prevent overheating of the mill. A large sample of such a mixture, prepared commercially for this laboratory had an average diameter of 3.9 microns. According to commercial sources, a minimum of about 70 per cent of diluent should be present for large-scale grinding of commercial DDT. Powders containing 20 to 25 per cent of DDT have been readily prepared in a laboratory hammer mill in comparatively large quantities.

The louse powder and the mosquito-larvicide dusts now in use by the armed forces are commercial grinds of DDT in inert carriers. Determinations of particle diameter on 22 samples of commercial

[1] This work was conducted under a transfer of funds, recommended by the Committee on Medical Research, from the Office of Scientific Research and Development to the Bureau of Entomology and Plant Quarantine.

louse powder gave an average value of 4.1 microns.

In the earlier stages of the work on DDT as an anopheline larvicide considerable emphasis was placed on the preparation of nonwettable dusts. Among many materials tested as diluents were stearic acid and metallic stearates. Stearic acid forms a solid solution with DDT. This solid solution can be prepared in various ways—by melting and grinding, by dissolving in a mutual solvent and evaporating and grinding, or by spraying the melted solution or the solution in a mutual solvent. It was possible to grind small quantities of this material in the laboratory to 14 microns. Several hundred pounds of this particle size were prepared by a commercial company by melting the two constituents and spraying. This gave a dust that was not readily wet by water. The material did not dust readily, but this property was markedly improved by the addition of calcium stearate. The addition of magnesium carbonate also increased the ease of grinding and dusting.

Mechanical mixtures of DDT and several metallic stearates were also made. It is possible with care to grind DDT with calcium stearate in a laboratory hammer mill. The addition of a small proportion of calcium stearate to a DDT-talc dust during grinding also decreases its wettability.

Over 4000 pounds of DDT dust mixtures have been prepared at this laboratory from technical DDT or from commercially prepared concentrated DDT dusts.

SOLUTIONS.—DDT will be widely used in solutions. It is moderately soluble in petroleum and vegetable oils and readily soluble in many common organic solvents. Solubility values have been determined in more than 100 solvents. The following tabulation gives the approximate solubility of pure DDT in a few of the more useful solvents at 27° to 30° C.:

Solvent	*Solubility* (grams DDT per 100 ml. solvent)
Cyclohexanone	100–120
Dioxane	91–100
Methylene chloride	84–91
Benzene	77–83
o-Dichlorobenzene	63–71
Tetrahydronaphthalene	63–71
Xylene	56–62
Acetone	50–55
Carbon tetrachloride	46–48
Benzyl benzoate	39–41
Dimethyl phthalate	31–33
Fuel oil, No. 2	ca. 10
Cottonseed oil	ca. 9
Stoddard Solvent	ca. 9
Kerosene, crude	ca. 8
Fuel oil, No. 1	ca. 8
Kerosene, refined	ca. 4
Ethyl alcohol, 95%	ca. 1.5

Technical samples of DDT are in general somewhat more soluble than the pure material.

The petroleum oils are being, and will no doubt continue to be, used in many large-scale applications of DDT. For example, kerosene solutions are recommended for residual sprays for flies, mosquitoes, bedbugs, and other insects, and solutions in fuel oil and higher boiling oils are recommended for use as anopheline larvicides. Underwear has been louseproofed by dipping in solutions of DDT in a volatile petroleum solvent. The solubility of DDT in impure petroleum oils varies with the lot of oil. Samples of kerosene and fuel oils other than those on which the solubilities given above were determined might be found to have higher or lower values.

Cyclohexanone has been used considerably at this laboratory as an auxiliary solvent to increase the solubility of DDT in petroleum oils. In general, when a 10 per cent DDT solution is desired, about 10 per cent of cyclohexanone has been added, and for a 20 per cent DDT solution about 20 per cent of cyclohexanone. The solubility of DDT in mixed solvents has not been completely worked out, but like other compounds it has been found to be less soluble in the mixture than would be expected from its solubility in each of the two components. For example, in a mixture of 20 parts of cyclohexanone and 80 parts of No. 2 fuel oil, from its solubilities in these two solvents alone the solubility of DDT might be expected to be 25 to 30 grams per 100 ml. of solvent at 27° to 30° C. Actually such a mixture dissolves only about 20 grams of DDT per 100 ml. Benzene, xylene, o-dichlorobenzene, and other materials have also been used as auxiliary solvents. To obtain 5 per cent solutions of DDT in purified kerosene, it is necessary to add an auxiliary solvent.

Because DDT is not very soluble in *Freon-12* (dichlorodifluoromethane), cyclohexanone and other solvents have been used to incorporate it in this solvent.

DDT is readily soluble in methyl chloride.

EMULSIONS.—Emulsions containing DDT have been found to have wide application in controlling insects affecting the armed forces. An all-purpose DDT emulsion concentrate should meet the following requirements:

(1) To reduce shipping space it should contain as high a concentration of DDT as is consistent with other requirements.
(2) It should mix with water readily and not require any special equipment for preparation of a good emulsion.
(3) It should form a good emulsion not only in soft waters but also in hard waters and in sea water.
(4) The emulsion should be reasonably stable at concentrations used in spraying (0.1 to 5.0 per cent DDT), but for most uses extreme stability is not necessary.
(5) The emulsion should be adaptable for use as a mosquito larvicide, as a residual spray for adult insects, and for as wide a variety of military uses as possible.

About 100 emulsifiers and combinations of emulsifiers have been tested with a large number of solvents. The choice of solvents is limited by the requirement of high solubility of DDT and that of low specific gravity, as well as availability in large amounts. For special purposes where these requirements do not have to be met many solvents may be used. Several aromatic hydrocarbons and commercial fractions containing them have given satisfactory emulsions. A concentrate containing DDT and an emulsifier in a water-immiscible solvent has been developed which forms a very stable emulsion in water.

Attention should be called to the fact that, although a 5 per cent DDT emulsion made from the above mentioned concentrate is more expensive than an equal amount of 5 per cent DDT solution in fuel oil or kerosene, a 1 per cent DDT emulsion is actually cheaper than 1 per cent solutions in these oils. Emulsions made from these concentrates have been used as mosquito larvicides, as residual sprays against mosquitoes, houseflies, bedbugs, etc., and in louseproofing clothing.

A moderately satisfactory emulsion can even be made by adding a solution of DDT in an aromatic hydrocarbon, with vigorous stirring, to a 1 per cent soap solution in water.

Other types of DDT emulsions have also been prepared. Several formulas for quick-breaking emulsions of fuel-oil solutions of DDT have been developed for use as mosquito larvicides. An emulsion containing DDT and other ingredients was recently adopted for use for the control of body, head, and crab lice.

SUSPENSIONS.—A simple type of aqueous suspension has been used in some of the work at this laboratory. Powdered DDT, usually mixed with talc, has been suspended in water in the presence of a wetting agent. This mixture must be kept agitated while in use. A similar suspension has been made by adding the DDT-talc dust to soapy water. Such suspensions have been found effective as residual sprays and have been tested as larvicides against culicine mosquitoes.

Some work has also been done on the preparation of colloidal or nearly colloidal suspensions of DDT. The DDT was dissolved in a water-miscible solvent with a wetting agent, and this solution was added to water. These suspensions are much more stable at very low than at high concentrations. For this reason they might be particularly useful as mosquito larvicides where long lasting is desired, as in cisterns, fire barrels, etc., and they have been used experimentally in these situations. They have also been tested as residual sprays.

MISCELLANEOUS PREPARATIONS.—A great many miscellaneous preparations of DDT have also been tried. One interesting development was the preparation of DDT "crayons" or sticks for use against cockroaches. These sticks when drawn across a surface left a good deposit of powder.

In experimental work on residual action against insects DDT has been incorporated in calcimine with effective results. DDT was also incorporated in furniture polish, oil paints, and lacquers. Applied in these vehicles the insecticide is indicated to be not fully effective but may have specialized uses.

SUMMARY.—Insecticidal preparations of DDT, developed for the control of insects affecting man, are described.

The most widely used DDT dusts are

the louse powder and the mosquito-larvicide dust. DDT is difficult to grind alone but may be readily ground with an inert diluent.

Solutions of DDT are being widely used and the solubility in several solvents is given. Petroleum-oil solutions can be used extensively as mosquito larvicides and as residual sprays.

Emulsions of DDT are perhaps the most versatile type of preparation. A suitable emulsion concentrate has been developed that meets the many requirements for the control of insects that affect man. It can be used as a mosquito larvicide, a residual spray, for louseproofing underwear, and for other insecticidal purposes.

Mechanical suspensions of DDT have some use as residual sprays. Colloidal suspensions have been found effective when used experimentally as larvicides.

DDT Powder for the Control of Lice Attacking Man[1]

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The remarkable performance of DDT against lice during the typhus epidemic in Naples, Italy, last winter has been widely proclaimed. DDT was first tested against the body louse; *Pediculus humanus corporis* Deg., at the Orlando, Fla., laboratory of the Bureau of Entomology and Plant Quarantine in November 1942. Since the early samples showed this material to be outstanding in toxicity and stability, the formulation of a suitable DDT louse powder was undertaken, and by May 1943 the 10 per cent DDT powder described in this paper was recommended to the armed forces and adopted for military use.

A brief summary of this work appears in a recent issue of this journal (Bushland *et al.* 1944a). A more detailed account, describing the methods used in developing this powder, including tests made in connection with relative effectiveness of various concentrations, choice of a diluent, methods of mixing, and particle size, is given in this paper. Although the experimental work was done principally with the body louse, DDT powder has also been found effective in destroying head lice, *Pediculus humanus humanus* L., and crab lice, *Phthirus pubis* (L.).

METHODS.—The techniques employed in the evaluation of DDT as a lousicide have been used by the writers in determining the effectiveness of a large number of organic compounds against lice (Bushland *et al.* 1945). Practically all new compounds are first tested by the beaker method. Compounds giving good kill of lice by this method are further evaluated by the arm-and-leg method. Materials that show promise as lousicides are then tested on grossly infested individuals.

Beaker tests.—Pieces of woolen cloth 1 inch square are impregnated by dipping in a 1.0 per cent solution of the toxicant, usually in acetone, but other solvents such as chloroform or benzene may be used. The solvent is allowed to evaporate, and the pads are placed in 50-ml. beakers. Ten lice are placed on the impregnated cloth, and mortality records are taken after 24 hours. Materials that allow no normal survivors after 24 hours are reinfested at various intervals to determine the duration of effectiveness.

Arm-and-leg tests. Most of the tests in the early evaluation of DDT were made by this method. The inner surfaces of arm-and-leg sleeves, made from winter-weight cotton underwear, are treated with a powder containing the desired concentration of the test material. The dosage, 3 grams per sleeve, is equivalent to about 2 ounces when applied to an entire suit of underwear. The sleeves are then placed on the arms and legs of research subjects, and 25 young adult lice are introduced and confined by sealing the bottoms and tops with adhesive tape. With compounds of unknown toxicity, the records are taken every 24 hours for the first 4 days and every 48 hours thereafter until normal lice are recovered. With compounds that are known to give kill for several days, the lice

[1] This work was conducted under a transfer of funds, recommended by the Committee on Medical Research, from the Office of Scientific Research and Development to the Bureau of Entomology and Plant Quarantine.
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[3] G. W. Eddy assisted in the project.

are not added until after the sleeves have been worn for about 4 days.

Tests on grossly infested subjects. In these tests approximately 500 young adult lice are introduced in the underwear of each man. Further to simulate natural infestation, cloth patches containing several hundred eggs in different stages of incubation are clipped to the underwear. After about 6 hours, when the lice have become established on the subjects, the garments are removed, the population of lice present is recorded, and, with the underwear turned inside out and spread on a table, 1 ounce of powder is applied uniformly to the inside of the underwear. Mortality records based on surviving lice are made at 24-hour intervals by examining the clothing for live lice. If the treatment proves effective, the subjects are required to wear the same underwear continuously, and at the beginning of the second week, without further treatment, additional lice are introduced. Additional reinfestations are made at the beginning of each succeeding week until a few normal lice survive longer than 48 hours, when for the purpose of these tests the treatment is considered to have failed.

EFFECTIVENESS OF DDT AT DIFFERENT CONCENTRATIONS.—*Results of arm-and-leg tests.* A large number of arm-and-leg tests have been conducted with different concentrations of DDT. Tests with 0.05 per cent of DDT have in no instance given complete kill of lice. However, 0.1 per cent has given complete kill in a few tests, but usually a small number have survived the treatment. With 0.25 per cent, lice introduced immediately after the sleeves were treated and again after 24 hours were killed, but the treatment was not completely effective after this time. The 0.5 per cent powder gave control for 2 to 3 days. A powder containing 1 per cent of DDT did not give complete kill longer than than 8 to 10 days, although it gave a high degree of control for several days afterwards. Sleeves treated with 5 per cent of DDT remained effective through 14 to 16 days' wearing. The duration of effectiveness of a 10 per cent powder was between 30 and 40 days. Even at 40 days only a small percentage of the lice escaped being killed during the 48-hour exposure.

There is a great deal of variation in the results obtained by the arm-and-leg method. No doubt several factor contribute to these variations. The more important causes appear to be related to host susceptibility. The temperature and humidity of the atmosphere and variations in resistance of the lice are probably also contributing factors.

Results of tests on grossly infested subjects. Results of the tests on grossly infested subjects are shown in tables 1 and 2.

Against the initial population all the powders were practically 100 per cent effective. The powders containing 1.25 and 2.5 per cent of DDT did not prevent establishment of newly hatched nymphs from eggs on the subjects at the time of treatment and did not control the reinfestation. Some of the adult lice introduced could not be accounted for 24 to 48 hours later, but practically all the surviving young nymphs could be found for some time after hatching. DDT is not ovicidal (the eggs on treated garments hatched nearly normally), but the residual effect of the 5 and 10 per cent concentrations prevented establishment of newly hatched nymphs during the period of the experiments. From the data shown in table 1 it was apparent that DDT in a louse powder should be used at a concentration higher than 2.5 per cent.

After the treated underwear had been worn for 7 days, and again on the tenth day, each subject was reinfested with 200 lice. The effectiveness of 5 and 10 per cent DDT powders after the treated garments had been worn for 7 days is shown in table 2. The 5 per cent DDT powder killed, within 48 hours, over 87 per cent and the 10 per cent DDT powder slightly over 99 per cent of the lice introduced on the tenth day after continuous wearing of the garments. The 10 per cent powder was clearly superior to the 5 per cent, which permitted a much higher percentage of lice to survive on the twelfth day.

The tests with the 5 per cent powder were therefore discontinued at the end of the twelfth day. The subjects wearing underwear treated with the 10 per cent powder were reinfested after 14 days, and again after 21 days. As indicated in table 2, the mortality of lice introduced after 14 days' wearing was nearly 100 per cent, and the treated garments remained highly effective after 21 days of continuous wearing.

A subject wearing an untreated garment was used during the experiments as

Table 1.—Mortality of lice obtained during first week following treatment of grossly infested subjects with powders containing various concentrations of DDT.

Concentration of DDT, Per Cent	Number of Lice Present at Time of Treatment	Per Cent Mortality of Original Infestation		Number of Lice Added at End of Second Day	Per Cent Mortality of Reinfestation		
		After 24 Hours	After 48 Hours		After 24 Hours	After 48 Hours	After 72 Hours
1.25	587	98.3	100	100	91.0	93.0	93.0
2.5	545	99.9	100	100	91.0	95.0	94.0
5	3410	99.7	99.9+	700	98.9	99.9	100
10	2236	100	100	600	99.9+	100	100

a control. During the first 3 days after introduction of the lice on the control the mortality was negligible. On the fourth day (eleventh day of the experiment) a slight natural mortality of lice occurred. The data from this control substantiate those from previous check tests, indicating that lice introduced on a man wearing untreated underwear will readily establish and survive in considerable numbers.

THE RECOMMENDED CONCENTRATION.—On the basis of the results obtained with these tests, a louse powder containing 10 per cent of DDT was recommended to the armed forces. DDT is of particular value as a louse powder because of its long-lasting qualities.

SPEED OF KNOCK-DOWN AND KILL.—Although lice exposed to the recommended concentration of DDT have not been known to recover, this compound is considered by some to be very slow in inducing lousicidal action.

To determine the speed of knock-down and kill of lice by DDT, 4 cloth pads 1 inch square were dusted with 10 per cent of DDT in pyrophyllite and placed in open Petri dishes. The lice were kept at 30° ± 2° C. and a relative humidity of about 85 per cent, and examined under the microscope after various periods of exposure.

Lice that could crawl with complete coordination of body movements were considered "normal"; those able to crawl but not with complete coordination were classified as "affected"; those not able to crawl but still alive as evidenced by leg, antennal, or gut movement were classed as "down"; and those showing none of these signs of life when examined under a microscope were classed as dead.

After an exposure of 1 hour 100 per cent of the lice were considered normal. After 3 hours 9 per cent were normal, 85 per cent were affected, and 2 per cent were knocked down. At the end of 4 hours 38 per cent were affected and 62 per cent were down. At the end of 6 hours all the lice were down, but none were dead. The first louse died after 8 hours' exposure, 50 per cent were dead after 13 hours, but not until after 20 hours did the last louse die. If viewed only with the unaided eye, most of the lice would be classified as dead after about 6 to 12 hours.

Table 2.—Mortality of lice introduced on grossly infested subjects after they had worn the treated garments a week or longer.

Days Treated Garments Were Worn Before Lice Were Introduced	Concentration of DDT Powder, Per Cent	Number of Subjects	Number of Lice Added	Per Cent Mortality at Indicated Number of Days After Introduction of Lice				
				1	2	3	4	5
7	5	7	1400	94.9	99.0	—	—	—
	10	6	1200	99.2	99.8	99.9	—	—
	0[1]	1	200	0	0	9.0	—	—
10	5	2	400	77.0	87.3	—	—	—
	10	6	1200	95.8	99.2	—	—	—
14	10	6	1200	96.2	97.9	98.6	99.4	99.9+
21	10	4	800[2]	84.1	91.9	93.2	94.1	96.0

[1] Untreated garment. [2] Newly hatched nymphs.

There is a marked difference in resistance to DDT between freshly fed lice and lice that have been starved for several hours. Many of the lice present on an infested individual are freshly fed, and probably very few have gone without a blood meal for more than 6 hours. Of the lice starved for 14 hours, 99 per cent were dead in 17 hours compared with 78 per cent of those freshly fed at the beginning of the test. Lice starved for 24 hours were down in 4 hours, whereas 6 hours' exposure was required to cause complete knock-down of lice not starved. Furthermore, all the lice deprived of a blood meal for 24 hours were dead in 13 hours, whereas 20 hours were required to kill all those that had been freshly fed. Under the conditions of these tests lice can be starved for 24 hours with negligible mortality and for 36 hours with only approximately 15 per cent natural mortality.

ABILITY OF LICE TO FEED AFTER EXPOSURE TO DDT.—The most important method by which typhus fever is transmitted is not through the bite of the louse directly, but as a result of the bite. The wound caused by the bite is infected with the *Rickettsia* organism through rubbing or scratching by the host. Therefore, if lice can be prevented from feeding they are less likely to transmit typhus.

Tests on the ability of lice to feed after being exposed to a 10 per cent DDT powder were made with 100 lice starved for 6 hours. Exposures up to 1 hour had no effect upon the ability of lice to take blood. About 80 per cent took blood meals 2 hours after treatment, and 45 per cent fed after 2.5 hours. Only 12 per cent were able to feed after 3 hours, and none after 3.5 hours. At this time only about 60 per cent of the lice were down. Therefore, it appears unnecessary to knock the lice down to prevent them from feeding.

COMPARISON OF SOME DILUENTS FOR DDT.—Since pyrophyllite is the carrier for many insecticidal powders and is used in the MYL powder (Bushland *et al.* 1944b), it was recommended to the Army as the diluent for DDT. Owing to its abrasive action on machinery, however, and since it might sometimes be desirable to use another diluent, a number of other carriers were tested.

The powders were prepared by two methods. In the first, or solvent-mix, method the carrier was thoroughly wet with an acetone solution of DDT, allowed to dry, and then ground to a fine powder on a glass plate. By this method the DDT is deposited on the carrier. In the second, or mechanical-mix, method the DDT was mixed mechanically with the diluent without the use of a solvent. In this method the DDT retains its original particle size, unless the mixture is subjected to grinding.

Four series of arm-and-leg tests were made with powders containing 1 per cent of DDT prepared by the solvent-mix method and one series with a 5 per cent DDT powder prepared by the mechanical-mix method. The tests in each series were run simultaneously, but the various series were run at different times. Therefore, a DDT-pyrophyllite powder was tested as a standard of comparison in each series. The sleeves dusted with the 1-per cent powders were infested immediately after treatment, but those dusted with the 5-per cent powders were worn 4 days before being infested. The results of these tests are presented in table 3.

Table 3.—Comparison of effectiveness of various diluents for DDT. Arm-and-leg tests.

Series	Diluent	Percentage of Lice Surviving When Introduced after Sleeves Had Been Worn after Indicated Number of Days								
		0	4	6	8	10	12	14	16	18
Powders containing 1 per cent of DDT, prepared by the solvent-mix method										
1	White wheat flour	0	0	10						
	Calcium carbonate	0	2	2[1]						
	Bentonite	21	—	—						
	Pyrophyllite (check)	0	0	1[1]						
2	Flowers of sulfur	0	0	0	0					
	Diatomaceous earth	0	0	0	0					
	Frianite (volcanic ash)	0	0	0	4					
	Pyrophyllite (check)	0	0	0	15					
3	Loomis talc	0	0	0	4	0				
	Inert "C" (a clay)	0	1	0	1	7				
	Pyrophyllite (check)	0	0	0	1	5				
4	Corn starch	0	0	0	0	0				
	Walnut-shell flour	0	0	0	0	0				
	Fuller's earth	0	0	0	0	1				
	Sacco Clay	0	0	0	0	1				
	Zinc oxide	0	0	0	0	8				
	Pyrophyllite (check)	0	0	0	0	5				
Powders containing 5 per cent of DDT, prepared by the mechanical-mix method										
5	*Sacco* Clay	—	0	0	0	2	1	4	4	13
	Inert "C"	—	0	0	0	1	4	1	11	12
	Kaolin	—	0	0	0	6	1	1	0	2
	Georgia talc	—	0	0	0	0	0	0	0	2
	Loomis talc	—	0	0	0	0	0	0	2	4
	Pyrophyllite (check)	—	0	0	0	10[1]	0	1	2	3

[1] Surviving lice not normal.

The 1 per cent DDT powder usually gave complete kill of lice through 8 to 10 days' wearing. In some tests the garments

remained effective through the 12th day, while in others normal lice were recovered on the 8th day. Any diluent containing 1 per cent of DDT that allowed normal survivors on the 6th day or a very large percentage on the 8th day was considered unsatisfactory.

The results with bentonite indicate that this diluent would prove entirely unsatisfactory when prepared by the solvent-mix method. Although both white wheat flour and calcium carbonate were inferior to pyrophyllite, their use might prove of value in certain instances. The three diluents tested gave good results in comparison with pyrophyllite, but the pyrophyllite used in this series gave results inferior to those usually obtained with this diluent. There appeared to be little difference between the diluents tested in series 3. *Inert "C"* was also tested in the 5 per cent powder. Good results were obtained with all the diluents tested in series 4.

The diluents in the 5 per cent DDT powders, prepared by the mechanical-mix method, gave somewhat erratic results. The Georgia and Loomis talcs appeared superior to pyrophyllite or kaolin, which, however, appeared to be better than *Inert "C"* or *Secco Clay*.

In other tests (Table 4) it is shown that bentonite, although unsatisfactory as a diluent for powders by the solvent-mix method, is effective when prepared by the mechanical-mix method. *Inert "C"* is an unsatisfactory diluent.

In tests on grossly infested men with 10 per cent of DDT mechanically mixed with pyrophyllite, Loomis talc, Georgia talc, and *Inert "C"*, the results substantiated those from the arm-and-leg tests in that pyrophyllite and the Loomis and Georgia talcs gave comparable results. The powder containing *Inert "C"* did not provide the full protection expected of powders containing this concentration of DDT.

In general, with the exception of bentonite, the various diluents showed no pronounced difference in effectiveness. Considering all factors, however, such as availability, suitability for use on the skin, and duration of effectiveness of DDT powders made from them, the diluents that appear to be best are pyrophyllite and talc. At the present time the louse powder is being manufactured with pyrophyllite by mechanical mixing, although certain grades of talc appear to be equally suitable.

METHODS OF MIXING.—Powders prepared by the two methods of mixing already described have been compared in arm-and-leg tests. In all routine tests of organic compounds as lousicides, the solvent-mix method has been followed. Theoretically, this method insures a complete and uniform coverage of each particle of the diluent with the test compound. However, preparations may be made more conveniently and cheaply by mechanical mixing.

A further comparison of powders prepared by the two methods of mixing is given in table 4. In these arm-and-leg tests 1 per cent of micronized DDT (6 microns) in various diluents was used. In one series the sleeves were infested immediately after treatment, and in another series they were not infested until the fourth day. It appears that the mechanical method of mixing is to be preferred. This was also demonstrated in tests on grossly infested men.

Table 4.—Comparison of solvent and mechanical methods of mixing DDT (1 per cent micronized) with various diluents. Arm-and-leg tests, 4 replicates.

Diluent	Method of Mixing	Percentage of Lice Surviving When Introduced After Sleeves Had Been Worn (Days)				
		0	4	6	8	10
Sleeves Infested Immediately After Treatment						
Pyrophyllite	Mechanical	0	0	0	0	12
	Solvent	0	0	0	1	5
Loomis talc	Mechanical	0	0	0	1	2
	Solvent	0	0	0	4	0
Inert "C"	Mechanical	1	0	0	0	2
	Solvent	0	1	0	1	7
Sleeves Infested on 4th Day after Treatment						
Bentonite	Mechanical	—	0	0	3	2
	Solvent	—	1	9	7	8
Pyrophyllite	Mechanical	—	0	0	0	2
	Solvent	—	0	0	1	2

EFFECT OF PARTICLE SIZE OF DDT.—The results of arm-and-leg tests conducted with 1 per cent DDT powders in which the DDT ranged in particle size from 6 to 17 microns are summarized in table 5. The differences could not be considered significant. Poor results were obtained with *Inert "C,"* which proved inferior to pyrophyllite or Loomis talc in other tests.

Similar tests of mechanically mixed powders containing 5 per cent of DDT in

Table 5.—Effect of particle size of DDT (1 per cent) when mechanically mixed with different diluents on its toxicity to lice. Arm-and-leg tests, 4 replicates.

Diluent and Particle Size of DDT[1]	Percentage of Lice Surviving When Introduced After Sleeves Had Been Worn (Days)			
	4	6	8	10
Pyrophyllite:				
17 microns	2	0	4	5
16 microns	0	0	1	2
11 microns	0	1	1	0
6 microns (micronized)	0	0	1	1
Check by solvent-mix method	0	0	0	0
Loomis talc:				
16 microns	0	0	1	
11 microns	0	0	0	
6 microns (micronized)	0	0	0	
Check by solvent-mix method	0	0	0	
Inert "C":				
17 microns	1	2	5	
16 microns[2]	0	0	4	
11 microns[2]	0	2	3	
6 microns (micronized)[2]	1	1	7	
Check by solvent-mix method	0	0	3	

[1] Values determined by air-permeation method.
[2] 8 replicates.

pyrophyllite were made on grossly infested men. DDT of 6, 11, 16, and 17 microns average diameter was used. Compared to the solvent-mix powder there was no appreciable difference in effectiveness of the various particle sizes.

EFFECT OF THE PARTICLE SIZE OF THE DILUENT.—Arm-and-leg tests with powders containing 1 per cent of DDT in pyrophyllite of varying particle size, prepared by the solvent-mix method, are summarized in table 6. The results indicate that particles of 5 microns or less were the most effective. It was also noted that powders of larger particle size did not adhere so well to the sleeves.

Table 6.—Effect of particle size of the diluent on the toxicity to lice of 1 per cent DDT-pyrophyllite powder prepared by the solvent-mix method. Arm-and-leg tests, 4 replicates.

Particle Size of Pyrophyllite (Microns)[1]	Percentage of Lice Surviving When Introduced After Sleeves Had Been Worn—(Days)			
	4	6	8	10
2.0	0	0	1	2
3.5	0	1	2	2
5.0	0	0	1	2
8.0	0	1	0	15
10.5	0	1	2	12

[1] Values obtained by air-permeation method.

The effect of the particle size of the diluent was also tested on grossly infested men using solvent-mix powders containing 5 per cent of DDT in pyrophyllite of 5.0 and 10.5 microns particle size. Both powders gave good control of the body louse, practically duplicating that from a powder made with standard pyrophyllite (2.0 to 2.5 microns). The powder made with pyrophyllite of 10.5 microns, however, was too coarse for practical use in dusting garments.

The standard pyrophyllite is used in the commercial louse powder. The average particle diameter of the 10 per cent mechanical-mix DDT louse powder now being made is about 4 microns.

EFFECT OF EXPOSURE TO HIGH TEMPERATURE.—A powder containing 10 per cent of DDT spread thinly on paper showed no signs of deterioration after being exposed in the laboratory for several months.

Another sample of 10 per cent DDT powder was exposed in uncovered watch glasses in a constant-temperature oven held at 60° C. (140° F.). After 1, 2, and 10 months' exposure, this powder was further diluted with pyrophyllite to 1 per cent DDT and used in arm-and-leg tests. At the end of the 10 months' exposure the powder was also tested without further dilution. At each examination the exposed powder was compared with a freshly prepared sample.

One month's exposure had no apparent effect upon the toxicity, for only 1 per cent of the lice introduced on the 10th day survived. After 2 months the DDT appeared to have lost some of its toxicity, but this loss was not considered important, since the six lice that did survive were not normal and all lice introduced on the tenth day were killed. When exposed for 10 months, the powder, after dilution to 1 per cent, allowed 48 per cent of the lice introduced on the 4th day to survive a 48-hour exposure. The 10 per cent powder, which when freshly prepared is effective for about 30 to 40 days, after 10 months allowed 4 per cent of the lice introduced on the 12th day and 15 per cent of those introduced on the 14th day to survive a 48-hour exposure.

Although the DDT had lost about half its toxicity after being exposed at 60° C. for 10 months, it is unlikely that in prac-

tice DDT would need to be stored so long at this temperature. These tests indicate that the DDT louse powder is not only stable under ordinary storage conditions but will also withstand elevated temperatures for fairly long periods.

WASHING DDT-TREATED GARMENTS.—Jones *et al.* (pp. 217–222) have shown that DDT-impregnated garments retain their lousicidal effectiveness even after several washings. To determine whether the same was true of garments dusted with DDT, several arm-and-leg sleeves were dusted with 3 grams each of 10 per cent DDT-pyrophyllite powder and then washed. After one washing in warm soapy water the sleeves gave complete control of lice upon 24 hours' exposure. After a second washing, however, a few lice survived. Similar results were obtained in tests on grossly infested research subjects.

SYNERGISTS FOR DDT.—More than 100 compounds have been tested as synergists for DDT against lice. These included all the materials that were found to be good synergists for the pyrethrins. The materials were tested at 2.0 per cent in combination with 0.025 per cent of DDT. Most of the materials proved of no value as synergists. A few appeared to increase the toxicity of DDT, but more data would be necessary to establish the fact.

ADDITION OF AN OIL TO DDT POWDER.—An attempt was made to prolong the effectiveness of DDT in powder form by the addition of an oil. It was thought that the oil might cause the powder to adhere more closely to the sleeves and thus reduce mechanical loss of the powder. A powder containing 5 per cent of DDT in pyrophyllite and 2 per cent of a commercial white oil (viscosity 75–80 Saybolt seconds at 100°F.) was compared with a similar 5 per cent DDT powder without oil. There appeared to be no difference in effectiveness between the two preparations.

It should also be pointed out that many of the synergists tried in combination with DDT were oily liquids. Although the tests were not designed to determine whether the materials would increase the lasting qualities of DDT, they did not increase its initial toxicity to any great extent.

DDT AND HEAD LICE AND CRAB LICE.—No research has been done on the use of a DDT powder for the treatment of head lice. A powder treatment for head lice would perhaps prove undesirable, since it is likely that most individuals would prefer using a liquid. It is believed, however, that a DDT powder would be effective. DDT has given excellent results against head lice when applied either in solution or in emulsion form (unpublished).

More than 100 cases of crab lice have been treated with the 10 per cent DDT powder. The lice present at the time of treatment were destroyed and a second application 8 to 10 days after the first was found to eradicate an infestation. No dermatitis has resulted from the use of DDT against crab lice in the cases treated by the authors.

SUMMARY.—DDT was tested first against lice at the Orlando, Fla., laboratory of the Bureau of Entomology and Plant Quarantine in November 1942. A louse powder containing 10 per cent of DDT in pyrophyllite was recommended to the armed forces in May 1943.

In arm-and-leg tests DDT at 0.25 per cent concentration caused complete mortality of body lice in 24 hours, but had little lasting qualities. Powders containing 1 per cent of DDT usually gave complete kill of lice for 8 to 10 days. A 5 per cent DDT powder was effective 14 to 16 days, and arm-and-leg sleeves treated with a 10 per cent powder generally gave complete kill for 30 to 40 days. In tests on grossly infested subjects a 10 per cent DDT powder gave practically complete kill of lice for 3 weeks.

All the lice exposed to a 10 per cent DDT powder were knocked down in 6 hours and were dead in 20 hours. Exposure to this powder for 3.5 hours prevented hungry lice from feeding. Lice starved for several hours were more susceptible to DDT than were freshly fed lice.

DDT mixed mechanically with powder diluents proved equally as effective as powders prepared by the solvent-mix method. Tests with various diluents indicated that pyrophyllite and certain grades of talc were the most suitable.

Within the range of sizes tested (6 to 17 microns) the particle size of the DDT did not appreciably influence the effectiveness of the louse powder. Dusts made with pyrophyllite diluent of particle sizes of 5 microns or less were more effective than those made with diluent of larger particle sizes.

A powder containing 10 per cent of DDT did not lose its effectiveness after several months' exposure to the open air

or when stored at 60° C. (140° F.) for 2 months. However, after 10 months' exposure at this temperature it lost about half of its toxicity.

Garments dusted with DDT remained effective against lice after one washing but was not effective after two washings in warm soap and water.

Of more than 100 compounds tested as possible synergists for DDT, none showed marked synergistic action. The addition of an oil to a 5 per cent DDT powder did not prolong its effectiveness.

The 10-per cent DDT powder was found highly effective against crab lice in the more than 100 cases treated.

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DDT Impregnation of Underwear for Control of Body Lice[1]

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The use of DDT (2,2-bis (p-chlorophenyl)-1,1,1-trichloroethane) in powder form for the control of lice affecting man has been described by Bushland *et al.* (1944a). DDT has also been tested extensively as a louseproofing agent for the impregnation of underwear, and the treatment has been developed to the point of practical use.

METHODS OF IMPREGNATION AND TESTING.—The methods used for treatment and testing of the garments were essentially the same as those already described for pyrethrum impregnation (Jones *et al.* 1944). In preliminary tests with DDT, however, treatments were made so as to obtain exactly comparable dosages in the garments. Thus in arm-and-leg tests all sleeves were treated with exactly 60 ml. of the DDT preparation, while complete two-piece suits of 50 per cent wool underwear were treated with exactly 1000 ml. of preparation. These were the amounts of liquid known to be just completely absorbed by the garments. Both solutions in volatile solvents and emulsions of DDT were used.

The entomological methods of testing were those described by Bushland *et al.* (1944b).

ARM-AND-LEG TESTS.—In some arm-and-leg tests cotton garments treated with a solution containing as little as 0.02 per cent of DDT gave complete control of lice as a fresh treatment, but failed to do so after 1 day. Garments treated with 0.05 per cent of DDT remained effective for more than a week of continuous wearing. Higher concentrations were effective for much longer periods.

In some of the early tests it was found that garments impregnated with DDT remained louseproof after laundering. The effect of laundering treated cloth with soap and hot water was therefore studied more extensively. In these tests the garments were washed at the end of each week's continuous wearing. The higher concentrations of DDT withstood washing remarkably well. Thus, garments treated with 1 per cent were completely effective after four washings, and were still highly effective after a fifth washing.

The tests shown in table 1 were run simultaneously and indicate the duration

Table 1.—Survival of lice in sleeves of cotton underwear cloth impregnated with solutions containing various concentrations of DDT and laundered before each infestation. 4 tests with 25 lice each at each concentration.

CONCENTRATION OF DDT (PER CENT)	PER CENT OF LICE SURVIVING 48 HOURS AFTER INTRODUCTION INTO SLEEVES ON INDICATED DAY AFTER IMPREGNATION					
	7th	14th	21st	28th	35th	42nd
0.05[1]	0	0	12			
	0	34				
.1	0	3				
.5	0	0	0	3	5	10
1.0	0	0	0	0	1	9

[1] In the first 2 tests at this concentration the sleeves were not washed.

[1] This work was conducted under a transfer of funds, recommended by the Committee on Medical Research, from the Office of Scientific Research and Development to the Bureau of Entomology and Plant Quarantine.

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of effectiveness of cotton sleeves treated with various concentrations of DDT in solution in a volatile solvent. The garments were laundered and dried before each infestation with lice.

The DDT treatment did not withstand dry cleaning so well as it did laundering; however, cotton garments treated with a 1 per cent DDT solution were effective after one dry cleaning.

Results of simultaneous comparative tests of cotton balbriggan cloth with 50 per cent wool regulation army underwear cloth using volatile-solvent impregnation are shown in table 2. In general there was no marked difference in effectiveness.

Table 2.—Survival of lice in sleeves of cotton and part-wool underwear cloth impregnated with solutions of DDT, with and without washing before each infestation. Each figure represents 2 tests with 25 lice each.

Concentration of DDT (Per Cent)	Treatment and Type of Cloth	Per Cent of Lice Surviving 48 Hours After Introduction into Sleeves on Indicated Day After Impregnation			
		7th	14th	21st	28th
0.05	Not washed:				
	Cotton	0	18		
	Wool	2	8		
	Washed:				
	Cotton	2	10		
	Wool	6	30		
.1	Not washed:				
	Cotton	0	0	4	18
	Wool	0	0	0	16
	Washed:				
	Cotton	0	8		
	Wool	0	2		

The use of emulsions of DDT for impregnation was compared with the volatile-solvent method. Garments treated with emulsions withstood washing well, in most cases as well as those treated with solutions. The tests shown in table 3 were run at the same time and show the period of effectiveness of washed and unwashed garments treated with emulsions of DDT. The results of simultaneous tests of cotton and wool garments treated with emulsions and of cotton garments treated with volatile-solvent solutions are summarized in table 4. There was an indication that when treated with emulsion wool withstood washing better than cotton, but this may be only because the cotton cloth is thinner and mechanical removal of DDT in laundering occurs more readily. It may be concluded in general that cotton and wool garments treated by either of the methods withstand washing about equally well.

Table 3.—Survival of lice in sleeves of cotton underwear cloth impregnated with DDT emulsions, with and without washing before each infestation; 4 tests with 25 lice each at each concentration.

Concentration of DDT (Per Cent)	Treatment	Per Cent of Lice Surviving 48 Hours After Introduction into Sleeves on Indicated Day after Impregnation		
		7th	14th	35th
0.05	Not washed	4	2	
	Washed	8	10	
.1	Not washed	0	6	
	Washed	2	10	
.5	Washed	0	2	
1.0	Washed	0	0	0[1]

[1] No survivors of lice introduced on the 21st and 28th days after impregnation.

Another scheme was also tried for impregnation. The inner surface of the arm-and-leg garment was dusted with DDT louse powder in the usual way; the garment was then turned right side out and ironed with a hot iron. Garments treated in this way with 3 grams of either 5 or 10 per cent powder gave complete control of lice after one washing and a fair degree of control after two washings, but they failed after the third washing. This treatment gave much shorter protection against lice under washing conditions than did a comparable dosage of DDT applied by impregnation from solution or emulsion.

Table 4.—Survival of lice in sleeves of cotton and part-wool underwear cloth impregnated with DDT emulsions, and of cotton sleeves impregnated with DDT solutions, when washed before each infestation; 4 tests with 25 lice each at each concentration.

Concentration of DDT (Per Cent)	Type of Cloth	Per Cent of Lice Surviving 48 Hours After Introduction into Sleeves on Indicated Day After Impregnation				
		7th	14th	21st	28th	35th
Emulsions:						
0.1	Wool	0	0	0	4	
	Cotton	0	8	34		
.5	Wool	0	0	0	0	14
	Cotton	0	0	0	12	14
Solutions:						
.1	Cotton	0	0	14		
.5	Cotton	0	0	0	0	16

Arm-and-leg garments impregnated with solutions of DDT in a volatile solvent and stored in a dark place for one year showed no indication of decreased effectiveness. Three concentrations on both cotton and 50 per cent wool gar-

Table 5.—Survival of lice in two-piece suits of 50 per cent wool underwear impregnated with solutions of DDT, with and without laundering before each infestation.

Concentration of DDT (Per Cent)	Dosage of DDT (Grams)	Subsequent Treatment	Per Cent of Lice Surviving 48 Hours After Introduction on Indicated Day After Impregnation											
			Initial	7th		14th		21st		28th		42nd		49th	
			Adults	Adults	Nymphs	Adults	Nymphs	Adults	Nymphs	Adults	Nymphs	Adults	Nymphs	Adults	Nymphs
0.1	1.0	Not washed	1	0	15	0	37	18	73						
		Washed	0	1	12	—									
.5	5.0	Not washed	0	0	0	0	5	0	10						
		Washed	1	0	32	—									
1.0	10.0	Not washed	0	0	0	0	0	0	2						
		Washed	0	—[1]		—[1]		0	0	0	1	0	4[2]	8	86
2.0	20.0	Not washed	0	0	0	0	0	0	0						
		Washed	0	0	0	0	0	0	0	0	0	0	0	0	0[3]

[1] Suit washed (one washing omitted) but not worn.
[2] No survivors of lice introduced on the 35th day after impregnation.
[3] No survivors of lice introduced up to the 70th day after impregnation, when 32 lice survived.

ments when tested in this way remained effective in killing introduced lice for about the same length of time and through as many washings as when they were freshly treated. Additional tests of storage of impregnated garments are underway.

TESTS ON GROSSLY INFESTED MEN.—The first suit tested, a heavy-weight cotton one treated with 3.25 grams of DDT in a 0.5 per cent solution in a volatile solvent, killed introduced lice for 6 weeks' wearing, during which time it was washed twice. After a third washing at the beginning of the seventh week it failed to give control in 48 hours, but did reduce the number of lice considerably.

Two-piece suits of 50 per cent wool regulation army underwear were then treated with 0.1 to 2.0 per cent of DDT in a volatile solvent to give total dosages of 1 to 20 grams of DDT per suit. Initial infestations were made with 400 to 500 adult lice, 400 eggs 4 to 7 days old, and 400 eggs 2 to 3 days old. Subsequent weekly infestations were with 100 to 200 adult lice and 100 to 200 newly hatched lice. For each dosage one set of suits was laundered at the end of each week's wearing, and another set was worn but not washed. The results are given in table 5. The suit with 20 grams of DDT showed remarkable resistance to laundering, giving complete control of lice introduced after the ninth washing and considerable reduction of lice even after 10 washings. A suit with 10 grams of DDT was highly effective after 5 washings. When underwear is washed once a week and the treatment is desired to last 6 to 8 weeks, a dosage 10 to 20 grams should be suitable.

In a similar series of tests, but using only two dosages of DDT, suits were treated with an emulsion of DDT. Infestations were made with several hundred lice as in the previous series, but no initial infestation was made. The results are shown in table 6. The suits appeared to remain effective longer than those treated with DDT solutions. Later tests, however, indicate that about the same period of effectiveness can be expected by the two methods.

Table 6.—Survival of lice in 50 per cent wool underwear impregnated with emulsions of DDT.

Concentration of DDT (Per Cent)	Dosage of DDT (Grams per Suit)	Subsequent Treatment	Per Cent of Lice Surviving 48 Hours After Introduction on Indicated Day After Impregnation[1]			
			28th		35th	
			Adults	Nymphs	Adults	Nymphs
0.5	5.0	Not washed	0	0	1	0
		Washed	1	0	7	26
1.0	10.0	Not washed	0	0	0	0
		Washed	0	0	2	3

[1] No survivors among lice introduced on 7th, 14th, and 21st days after impregnation of suits.

DEVELOPMENT OF METHODS OF TREATMENT.—The foregoing work established the dosages necessary to give effective control of lice. The next step was to develop methods whereby the impregnation of underwear could be put into practical use both overseas and in this country. Treatment with emulsion appeared to be the best method for impregnation overseas, and treatments in this country could be made either with emulsion in laundry equipment or with volatile-solvent solutions in dry-cleaning equipment.

FIG. 1.—Portable outfit for louseproofing underwear by impregnation.

Outfit for Overseas Use.—A portable outfit for moderately large-scale treatment of underwear overseas was developed by Randall Latta, of the Division of Control Investigations of the Bureau. This outfit is shown in use in fig. 1. It consists of a 36-gallon army water-sterilizing bag mounted on a four-legged frame to which a wringer is clamped. A thorough test was made of this apparatus. Thirty gallons of emulsion were prepared in the bag at a concentration of 1 per cent of DDT. Two-piece 50 per cent wool army underwear was used. All clothing was weighed before treatment. It was desired to obtain approximately 10 grams of DDT per suit. A few suits of summer underwear were also treated.

Three men were used for the operation—one to dip the underwear and start it through the wringer, one to turn the wringer, and the third to take the underwear from the wringer and hang it up. Tongs were used for handling the garments during dipping.

The procedure was as follows:

(1) A sample of the emulsion was removed for chemical analysis and for subsequent treatment of sleeves for arm-and-leg tests.

(2) Two suits were then dipped and weighed to determine the amount of emulsion taken up and to make any necessary adjustment of the wringer.

(3) Four suits were dipped for use in tests on grossly infested men, and exact dosages were determined by weighing.

(4) A large number of suits were dipped until the bag appeared to be about half full; the time required to dip these suits was recorded.

(5) Another sample was removed for chemical analysis.

(6) Four suits of cotton summer underwear (sleeveless shirts and shorts) were dipped.

(7) Dipping of a large number of part-wool suits was resumed, and the time recorded, until the bag was nearly empty.

(8) Four suits were dipping for tests on grossly infested men.

(9) A number of additional suits were dipped.

(10) Another sample was taken for chemical analysis and arm-and-leg tests.

(11) Additional suits were dipped until not enough emulsion remained to treat any more.

(12) The volume of the remaining emulsion was measured.

A total of 115 suits, or 174 pounds, of 50 per cent wool underwear were dipped. This underwear required 27.44 gallons of emulsion (0.16 gallon per pound of underwear) or 903 ml. per suit, an average dosage of 9.03 grams of DDT per suit. At this rate and allowing for excess at the end, 30 gallons of emulsion made from 1½ gallons of concentrate will treat 124 suits, or 186 pounds, of this type of underwear.

The time for the entire experimental operation was about 3 hours. An average taken from the intervals when dipping of 90 suits was timed showed that the actual

treatment required 45 seconds per suit. The treatment of 124 suits would then require 93 minutes. The emulsion had no effect on the rubber lining of the bag or on the rubber rollers of the wringer.

Rough chemical analysis of the samples taken was made by extraction of the emulsion with ether and crystallization of the DDT by addition of water to an alcohol solution of the ether extract. The results showed no appreciable change in the concentration of the emulsion during the dipping.

For arm-and-leg tests against lice the samples of emulsion were diluted to give 0.1 per cent of DDT. The results were similar to those obtained in previous tests of sleeves treated with 0.1 per cent emulsion, indicating no change in DDT content of the emulsion during dipping.

The part-wool suits tested on grossly infested men, including washing once a week, gave results similar to those obtained in previous tests with suits treated with 10-gram dosages of DDT. This was further indication that emulsion treatment was fully as effective as treatments in solutions.

The treated summer underwear also gave good control of lice. After one washing the suits killed all introduced lice in 48 hours, and after a second washing 1 week later they gave better than 90 per cent control of introduced lice.

Use of Large-Scale Laundry Equipment.—With the cooperation of the Offices of the Surgeon General and the Quartermaster General, a large-scale treatment of underwear with DDT emulsion was next undertaken. The usual large-scale laundry equipment was used. The impregnation was designed to louseproof the garments for 6 to 8 weeks' wearing, allowing for washing once a week. From previous experience it was known that this would require about 15 grams of DDT per suit of part-wool underwear. Since the average dry weight of these two-piece suits is 750 grams, the dosage desired was 2 per cent of the weight of the underwear. The garments were regulation army 50 per cent wool underwear, with a few suits of cotton summer underwear.

To determine the concentration of emulsion to be used and the amount of wringing necessary, a trial run of 10 suits was first made. To obtain the desired dosage of 15 grams these suits were treated with a 2 per cent DDT emulsion and the extraction was adjusted so that the suits would retain 100 per cent of their weight of emulsion—i.e., the wet weight of the suit to be double the dry weight.

The following general scheme was then followed: A lot of 60 gallons of emulsion was prepared in the wash wheel. A batch of 80 garments (40 suits) was added. This allowed 1½ gallons per suit, which thoroughly wet the garments. The batch was agitated in the wash wheel for about 2 minutes. The garments were removed to a portable drain tub and then transferred to the centrifugal extractor, which was then turned on for 30 seconds. The garments were placed in tumblers until dry. All drainings from the tub and the extractor were returned to the wash wheel, and sufficient fresh emulsion was added to bring it to the original volume. A second batch of 80 pieces was then treated in the same way. This was repeated until 10 batches of garments had been so treated. All used emulsion was then discarded, a fresh 60-gallon lot was prepared, and 10 batches of garments were dipped as before. This scheme was continued throughout the treatment.

Altogether about 5300 part-wool suits were treated. One batch of 50 suits of cotton underwear was also treated. One hundred and eighty-seven gallons of concentrate were used. The treatment required 45 hours, or an average of about 120 suits per hour. The drying time extended beyond this 45-hour period. If this method is employed, the concentration of the DDT emulsion should be increased to permit more complete removal of liquid in the extraction process without decreasing the dosage of DDT per suit, and thus decrease the drying time. In practice the rate of treatment could be greatly increased over that in this experimental impregnation.

Chemical analyses of various lots of the emulsion and of a sample of treated underwear were made by S. A. Hall *et al.* (1944). An average of seven samples of the emulsion taken at different times during the treatment gave 1.86 per cent of DDT. Although analyses of the first lot of emulsion indicated a possible reduction in the DDT concentration during dipping, this was not borne out by analyses of a later lot of emulsion. A sample of underwear taken at random during the treatment

was later analysed and found to contain about 2.5 per cent of its dry weight of DDT.

The principal checking of the DDT content of the garments was done by weighing them before and after treatment. A large number of garments were weighed before treatment to obtain an average dry weight. Samples of wet garments from the extractor were weighed from all of the first 10 batches and then at frequent intervals throughout the treatment. The average dry weight per suit of 50 per cent wool underwear was 744 grams, the wet weight 1564 grams, giving an average retention of emulsion of 820 grams per suit. At 1.86 per cent DDT this amounts to 15.2 grams of DDT per suit, or slightly over 2 per cent of the dry weight of the suit.

Suits for tests on grossly infested men were treated in duplicate at various stages of the process. These suits were worn 23 days and were laundered nine times. After the seventh washing almost complete control of lice was obtained in 48 hours. After the eighth washing on an average about 2 per cent of the lice survived, and after the ninth washing there were about 7 per cent of survivors. The suits thus gave the expected control of lice after seven to eight washings. Entomological tests gave no indication of a reduction in DDT content of the emulsion during the treatment. Suits from the tenth batch were equally as effective as those from the first batch dipped in a given lot of emulsion.

One suit from this treatment worn continuously but not washed killed all lice within 48 hours after infestation at the end of 6 months' wearing, when the test was discontinued. It is therefore seen that washing is the principal factor in loss of effectiveness of the DDT, and that treated garments washed less frequently than once a week or laundered less vigorously than in these tests could very well remain effective for the serviceable life of the underwear.

Suggestions for Use by Armed Forces.—On the basis of these tests a dosage of 2 per cent of the weight of the cloth has been recommended for use by the armed forces. If the underwear is to be treated in this country, it would be preferable to use volatile solvent solutions in dry-cleaning equipment. Arrangements could even be made to treat the cloth before preparation of the garments.

If the impregnation is done overseas, or if reimpregnation is necessary, several schemes, all based on the use of an emulsion, are possible. The mobile laundry units, which are similar to, but smaller than, the unit used for the large-scale test impregnation, could be used. For treatment in more advanced areas the portable impregnation unit described above could be adopted. Finally, each individual could treat his own underwear in a bucket, or even in his helmet if necessary. If rapid drying were desired, the suit could be treated with only 1 pint of a 2 or 2.5 per cent emulsion, barely enough to wet the suit. Either the garments should be dry when treated or the concentration of DDT should be sufficiently high to allow for dilution by the water in the garments. Schemes for spraying the underwear, as was done in tests here with pyrethrum treatments (Jones *et al.* 1944), with a minimum amount of emulsion could also be employed.

Incidentally, DDT impregnation also mothproofs garments; this treatment would therefore simplify the problem of storing woolen underwear.

SUMMARY AND CONCLUSIONS.—The impregnation of underwear with DDT has been investigated as a means for the control of lice affecting man. Cotton and 50 per cent wool garments were treated, with various concentrations of solutions and emulsions of DDT, and lice were introduced at various intervals after the treatment. Some garments were worn without laundering; others were washed periodically.

In arm-and-leg tests garments treated with 0.05 per cent of DDT in solution remained effective for more than a week's wearing. Garments impregnated with 0.5 per cent DDT solutions were completely effective after three weekly washings; those treated with 1.0 per cent were completely effective after four washings. In general about the same duration of effectiveness can be expected from treatments with solutions and emulsions of DDT. Arm-and-leg garments treated with DDT solutions showed no decrease in effectiveness after being stored for a year.

Whole two-piece suits of 50 per cent wool underwear receiving a dosage of 10 grams of DDT remained highly effective after five washings, and suits receiving 20

grams of DDT through nine or ten washings. On this basis a dosage of 15 grams, equivalent to 2 per cent of the weight of the garment, is recommended to give protection against lice through six to eight washings.

Practical methods for impregnation of underwear with DDT have been developed. A portable outfit making use of a 30-gallon army water-sterilizing bag was found to be entirely feasible. One filling of the bag was sufficient to impregnate 124 suits, or 186 pounds, of part-wool underwear. A large-scale treatment was made in standard laundry equipment. Over 5000 suits were treated with emulsion to give a dosage of 2 per cent of the weight of the garment. Suits from this treatment gave protection through six to eight washings. An unwashed suit was still killing all introduced lice after 6 months' wearing.

It is suggested that if underwear is to be impregnated with DDT in this country volatile solvent solutions be used in dry-cleaning equipment. For louseproofing underwear overseas an emulsion is recommended. The impregnation could be carried out in mobile laundry units, in the portable unit described herewith, or by the individual in any suitable small container.—1-23-45.

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DDT Residual Sprays Applied in Buildings to Control *Anopheles quadrimaculatus*[1]

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During the course of investigations being conducted at the Orlando, Fla., laboratory of the Bureau of Entomology and Plant Quarantine the discovery was made in the spring and summer of 1943 (Gahan *et al.* 1945a) that DDT sprays applied to wooden or canvas surfaces leave a residue that remains toxic to adult mosquitoes for an indefinite time. Field tests conducted the same year in buildings naturally infested with mosquitoes demonstrated that this method of control was effective under practical conditions (Gahan *et al.* 1945b). Publication of the original results was delayed for security reasons. The information, however, was freely disseminated by personal communication to authorized personnel, so the method could be used in actual mosquito control and to encourage further research.

Other workers have demonstrated that malaria can be controlled by weekly spraying of buildings with pyrethrum, but they have not shown a significant reduction in number of mosquitoes occurring in the neighborhood.

By way of continuing the work reported previously, a large-scale practical test was conducted near Stuttgart, Ark., during the mosquito season of 1944 to determine the duration of effectiveness of a single application of DDT residual spray against the common malaria mosquito in this country, *Anopheles quadrimaculatus* Say, and to ascertain whether the general population of this species occurring in the immediate vicinity of sprayed buildings could be reduced by employing this method without the assistance of other control measures.

Stuttgart is located in one of the largest rice-growing sections in the United States. This crop is grown in fields that are flooded with water during a large portion of the

[1] This work was conducted under a transfer of funds, recommended by the Committee on Medical Research, from the Office of Scientific Research and Development to the Bureau of Entomology and Plant Quarantine.

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growing season, and excellent habitats are available for the development of tremendous populations of mosquitoes. Adults of *Anopheles quadrimaculatus* are numerous from June to October and cause trouble in buildings that are not well screened. In spite of the very high population of potential carriers found in this locality, the incidence of malaria is reported to be very low. Therefore, no attempt was made to obtain direct information of the effectiveness of DDT residues as a control measure for this disease.

The inside walls and ceilings of nearly all buildings and the under side of all bridges and culverts in two areas, each of which contained 9 square miles in the shape of a square, were sprayed with DDT. No other control methods were used. These areas were ideally situated for obtaining favorable results in that there were few trees and a large proportion of the *Anopheles* adults were forced to seek buildings as resting places rather than heavily wooded areas. On the other hand, the buildings were not evenly distributed, but were grouped into farm units frequently one-half mile or more apart.

Sprays were applied by laborers of the U. S. Public Health Service with a small orchard-type power sprayer that was mounted on a truck. To lessen wastage of material, a bamboo extension rod was fastened to the end of the hose line, thereby enabling the operator to raise the single nozzle at least 15 feet into the air when spraying the inside of tall buildings. It was not found practical to spray the highest portions of some barn roofs or underneath all houses, because they could not be conveniently reached, nor was an attempt made to get inside of well-furnished dwellings that were screened. Spraying was confined largely to outbuildings, although houses that were poorly constructed were also treated. It is believed that 75 per cent of the surfaces which *Anopheles* mosquitoes are known to use as resting places in each area were coated with DDT, although in the absence of a full understanding of where adult *Anopheles* rest this is a matter of conjecture. Application was started on May 5 and completed on June 8, a total of 280 man-hours of labor being required for the work.

Two types of carriers were used for the DDT, kerosene solutions and water emulsions. Approximately half of the buildings in each area were treated with each spray. Kerosene caused severe irritation to the operators while they were spraying high ceilings. At times they held the spray rod almost directly overhead, and droplets of liquid that did not adhere to the wooden and metal surfaces fell onto their faces and hands. Two operators developed small blisters on the backs of their hands, and all three complained of their eyes smarting and foreheads stinging. When water emulsions were applied, no blisters formed and the only irritation noticed was temporary smarting of the eyes if unusually large droplets fell into them.

In one area an estimated 504,103 square feet of surface was sprayed with 599 gallons of material containing 1.25 cent per cent of DDT to obtain an average deposit of 56 mg. of DDT per square foot. In the second area sprays containing 5 per cent of DDT were employed, 399 gallions being used on approximately 363,588 square feet of surface at the rate of 208 mg. of DDT per square foot. A total of 588 buildings, ranging in size from privies to a large grain elevator (39,700 square feet), and 99 bridges or culverts were treated. Small chicken coops, barrels, boxes, and other miscellaneous pieces of equipment were also sprayed. Approximately 62 pounds of DDT were used in the light-dosage area and 167 pounds in the area receiving the heavier deposit. This portion of the work was completed before mosquitoes became numerous in the buildings. Only an occasional one was noticed while spraying was in progress.

Three methods of determining the effectiveness of these treatments were used: (1) The degree of protection being maintained in treated buildings was observed by counting the adults; (2) the mosquitoes resting in untreated nail kegs placed at random in the areas were counted to determine the relative abundance of adults occurring in the general vicinity; and (3) the larval population was sampled in all areas by dipping in rice fields. Comparisons were made with similar areas nearby that were untreated. All areas used were similar in that rice fields were plentiful, the same methods of raising the crop were used throughout, and adult mosquitoes were formerly abundant in all unscreened buildings that were not sprayed. It was assumed that the distribution of *Anopheles*

Table 1.—Adult mosquitoes counted during the afternoon in small buildings in two areas treated with DDT residual sprays and in untreated areas nearby.

Date of Count		Buildings Examined		Mosquitoes Counted				Per Cent Control
				Total		Average per Building		
		Treated	Untreated	Treated	Untreated	Treated	Untreated	
Treated area sprayed May 21 to June 8 at rate of 56 mg. per sq. ft.								
June	21–22	27	11	1	661	0.04	60	99+
	27–28	28	21	41	1,592	1.5	76	98
July	11–12	29	24	5	1,147	.2	48	99+
	26–27	29	24	25	1,097	.86	45	98
August	9–11	28	24	734	12,874	26	536	95
	19	29	24	2543	11,322	88	472	81
	26	29	24	2209	23,600	76	983	92
September	1	24	21	892	13,419	37	639	94
	14–15	26	24	1459	10,114	56	421	86
	24	27	24	348	2,859	13	119	89
Total or average		276	221	8257	78,685	30	356	91
Treated area sprayed May 5 to 20 at rate of 208 mg. per sq. ft.								
June	20–23	17	18	10	1,460	0.58	81	99+
	29–30	32	18	4	915	.1	51	99+
July	14–15	35	29	4	1,950	.1	67	99+
	29	33	28	21	2,639	.64	94	99+
August	10–11	33	29	82	13,789	2.5	475	99+
	18	33	29	265	13,499	8	465	98
	25	33	29	426	11,227	13	387	97
September	2	29	29	52	13,370	2	461	99+
	12–13	33	29	140	21,313	4	735	99+
	25	33	29	43	2,261	1.3	78	98
Total or average		311	267	1047	82,423	3	309	99

mosquitoes around Stuttgart is uniform throughout the entire locality, and that most of the adults do not fly over 1 mile from their breeding source. If this assumption is correct, the center square mile of each treated area should have been relatively free of mosquitoes that infiltrated from outside the treated zone.

ADULT COUNTS IN BUILDINGS.—The adult mosquitoes resting in treated and untreated buildings during the afternoon were counted at weekly or biweekly intervals between June 20 and September 25. Since practically all rice fields had been drained prior to the latter date and the numbers being found in buildings were declining rapidly, systematic checking was then discontinued. An additional observation was made between October 17 and 19, to obtain records as late in the season as possible. However, an average of less than one mosquito was observed per building in the two untreated areas, and it was apparent that the mosquito season had nearly ended. The results obtained at this time were therefore not included in evaluating the test.

No attempt was made to examine every building, since the labor involved would have required a much larger staff than was available. A number of small buildings, principally chicken houses and pump houses, were selected as checking stations and compared throughout the season with similar buildings located at least 1 mile outside of the treated areas. All are recognized to be good resting places for adults of *Anopheles quadrimaculatus*. Since DDT has been found slow acting (Gahan *et al.* p. 236), most records were taken during the afternoon to allow the chemical sufficient time to act on the mosquitoes. On three occasions examinations were also made immediately after sunrise.

The mosquitoes resting in treated buildings were actually counted every time an observation was made. The same method was used in untreated buildings during the early part of the season, but in August the numbers became so high that

Table 2.—Adult mosquitoes counted during the early morning hours in small buildings in two areas treated with DDT residual sprays and in untreated areas nearby

Date of Counts	Buildings Examined		Mosquitoes Counted				
			Total		Average per Building		
	Treated	Untreated	Treated	Untreated	Treated	Untreated	Per Cent Control
Treated area sprayed at rate of 56 mg. per sq. ft.							
July 11–12	29	24	247	1,384	9	58	84
August 19	29	24	4085	11,383	141	474	70
September 1	24	21	3265	12,662	136	603	77
Total or average	82	69	7597	25,429	93	369	75
Treated area sprayed at rate of 208 mg. per sq. ft.							
July 14–15	35	29	108	2,478	3	85	96
August 18	33	29	1256	13,148	38	453	92
September 2	29	29	805	12,486	28	431	94
Total or average	97	87	2169	28,112	22	323	93

it was impossible to count them accurately. After that time conservative estimates were made in a large proportion of the stations.

It is readily apparent from the results in table 1 that a single application of DDT greatly reduced the numbers of mosquitoes resting in the sprayed buildings during the daytime throughout the entire mosquito season. In 10 series of afternoon observations, the last of which was made 3.5 to 4.5 months after the sprays had been applied, a reduction of over 99 per cent for the 208-mg. treatment and 91 per cent for the 56-mg. application can be claimed, if the numbers found in untreated buildings are considered the normal population that would have been present had no spray been employed. Almost half, or 3953, of the 8257 mosquitoes observed in the lightly treated buildings were found in two chicken houses that had been sprayed by the owners the previous year with waste lubricating oil. Elimination of these two stations would have increased the degree of protection to 95 per cent. A similarly treated chicken house in the heavily treated area was also relatively ineffective after July. The effect of this material on the DDT has not been determined. Except in the buildings just mentioned, the heavy deposit showed no appreciable loss in toxicity throughout the entire season, but the light deposit gave somewhat poorer protection during August and September than throughout June and July. Residues obtained from the kerosene solution and the water emulsion appeared to be equally effective.

It is common knowledge that *Anopheles quadrimaculatus* adults seek shelter in buildings during the daylight hours. Observations made shortly after dawn should record the maximum number that are present in the DDT-treated buildings at any one time during a 24-hour period, since most of those present will not have contacted the chemical residue long enough to become activated by it.

On three occasions during July and August all checking stations were examined twice, once as soon after sunrise as possible and again the same afternoon. More mosquitoes were found in the treated buildings in the morning than in the afternoon (compare tables 1 and 2), but less than 10 per cent as many were observed in the heavily treated buildings as in others that had not been sprayed. Reductions ranging between 70 and 84 per cent were also indicated in the lightly treated buildings. Over half (85 and 55 per cent) of those observed in both areas during the morning had disappeared by midafternoon.

It is doubtful whether these counts show definitely that the number of adults occurring in the general vicinity had been greatly reduced, because mosquitoes undoubtedly entered throughout the night and after contacting the chemical disappeared again before morning In contrast,

a much larger proportion of those entering untreated buildings probably remained until dawn. As many as 450 have been seen resting on the walls of an untreated chicken house at 10:30 p.m. The fact that mosquitoes actually do come into buildings and remain on treated surfaces for a short time undoubtedly increases the potentialities of DDT sprays as a control for malaria, for it shows that the chemical is not highly repellent and some mosquitoes that feed on infected hosts will remain in contact with the DDT long enough to obtain a lethal dose and die before they reach the infective stage.

In untreated buildings between July 11 and 15 (Table 2) fewer mosquitoes were observed during the afternoon than in the morning, but the reduction was only approximately 20 per cent as compared with over 95 per cent in the treated buildings. These observations were made during an extremely warm period when official temperatures averaged between 100° and 106° F. during the warmest part of the day. Most of the buildings became extremely hot, and the mosquitoes undoubtedly sought cooler resting places, probably beneath the floor where they could not be seen. On the other hand, August temperatures were somewhat lower, and in some buildings many more mosquitoes were counted during the afternoon than immediately after sunrise. In the morning they could be seen in all parts of a building, but during the hotter part of the day most of them were found in corners close to the floor, and in some pumphouses they were actually resting on the soil. These observations show rather conclusively that mosquitoes sometimes change their resting places during the daylight hours. They also suggest that some of the mosquitoes found in treated buildings during the afternoon might have entered a short time before examinations were made and consequently had not rested on the DDT sufficiently to obtain an activating dose.

Most of the mosquitoes that contact DDT residues in unscreened buildings fly out open windows or doors and escape before being knocked down. While previous tests had already indicated that DDT kills most of these mosquitoes (Gahan *et al.* p. 231), three additional tests were conducted in conjunction with this project. Adults that had been trapped in unsprayed barns and sheds were released in three of the buildings treated with the 56-mg. dosage. As the mosquitoes attempted to escape, they were collected at closed windows or on screens and transferred to untreated wire cages. A few attempted to leave within 10 minutes after being released, and a total of 159 adults were caught within 5 hours after being exposed to the residues. Some of them were so seriously affected that they were barely able to fly. Ninety-two per cent died within 24 hours. Unfortunately the weather was extremely hot when these tests were made, and this factor undoubtedly contributed to a mortality of 53 per cent among 83 mosquitoes used as checks. All buildings used had been sprayed at least 40 days previously.

Although the percentage reduction figures indicate that excellent protection was obtained in both treated plots, the buildings sprayed at the rate of 56 mg. per square foot contained 10 times as many mosquitoes during the afternoon and 4 times as many immediately after sunrise as those treated with the 208-mg. dosage. The average per building once remained as high as 88 during the afternoon. Since it is desirable to eliminate as many mosquitoes as possible, the heavier deposit is the preferable one to use under the population conditions occurring around Stuttgart. In other sections of this country where only a small number of mosquitoes is encountered, the light deposit may suffice.

COUNT OF ADULTS IN NAIL KEGS.—An attempt was made to determine the relative abundance of *Anopheles quadrimaculatus* adults inside and outside the treated areas, by placing nail kegs at random under bushes and trees bordering roads. The second week in July, 20 kegs were put in each sprayed area, the majority of them being located close to the middle square mile and all of them at least one-half mile inside the nearest border. The same number were scattered throughout two 9-square-mile areas that had not been treated. In August, 10 more kegs were set out in each treated area and 20 were distributed around 3 sides of these areas 1 mile outside the nearest border.

Between July 12 and August 26 the first 20 kegs placed in each area were examined for adults 14 times, while those added in August were checked 6 times. It was not possible always to examine every keg, as

some of the roads occasionally were so muddy that they were impassable. Shortly after this method of sampling was started, it became obvious that the largest counts could be obtained during the morning hours, since the high temperatures prevailing later in the day caused many of the insects to leave in search of cooler resting places. For this reason all examinations were made before 1 p.m.

Although adults were numerous in some of the kegs, it is believed the results were too erratic to give an accurate indication of the adult population actually present. A summary of these counts is shown in table 3.

Table 3.—Adult mosquitoes obtained in nail kegs placed at random in two areas treated with DDT and in untreated areas nearby.

Area	Number of Observations	Mosquitoes Counted	Average per Observation
Treated at rate of 56 mg. per sq. ft.	308	10,341	34
Untreated	363	9,150	25
Treated at rate of 208 mg. per sq. ft.	315	6,453	20
Untreated	393	9,544	24

When no attempt is made to select the kegs that are used in evaluating the results, a reduction of 17 per cent is indicated in the heavily treated area, but an increase of 36 per cent in the lightly treated one. Many of the kegs that were placed around three sides of the sprayed areas during August were set in locations that obviously were less favorable than those occurring inside the areas that were sprayed, because the territory was less thickly inhabited and only an occasional building was seen. Extremely low counts were obtained throughout these sparsely settled sections.

If the comparison is based on the first group of 20 kegs that were set out, 21 per cent fewer mosquitoes were found in the area sprayed with the 208-mg. dosage and 10 per cent fewer in the one sprayed with 56 mg. than in their corresponding checks. Even in this group, however, the catches in individual kegs from day to day and throughout the test period varied tremendously. On a single day 3 or 4 kegs often contained as many as 100 to 400 adult mosquitoes, but many of the others harbored less than 10 and sometimes none. Reductions of 37 and 39 per cent could be claimed for the treatments by merely eliminating from consideration the two kegs in each sprayed area that caught the highest total number of mosquitoes during the test period.

It is apparent that the selection of keg locations can have considerable effect on the results that are obtained. To obtain accurate comparisons with this method of evaluating relative adult densities, a preliminary study probably should be made some time prior to the application of the sprays to ascertain definitely that the keg sites being used in the treated and untreated areas are equally favorable. Since the treatments were applied before the mosquito season started, such a study was not made.

COUNTS OF LARVAE OBTAINED BY DIPPING.—Between June 20 and September 6 the relative abundance of *Anopheles* larvae in the two treated areas and in others that were not treated was determined by dipping in rice fields in these areas. These fields were not ideal for this purpose, because the water was removed from them several times during the season and consequently the surface available for breeding purposes varied from week to week. However, the same methods of rice culture were followed by all farmers, and conditions were comparable between the treated areas and their corresponding checks for basing conclusions on a full season's work. Late in August and early in September the farmers began draining their fields for the last time, and dipping was discontinued. The rice planted in the vicinity of the lightly treated area was flooded 2 weeks longer than around the heavily treated one, consequently two additional records were obtained in these fields.

Five untreated areas were used in making comparisons with the two areas that were sprayed. On June 21 all dips were made in a tract located several miles southeast of the lightly treated area. This tract contained only a few buildings. Since it was likely that the absence of favorable resting places might reduce the numbers of *Anopheles* mosquitoes in the vicinity, the remainder of the dipping in June and during most of July was done in two 9-square-mile blocks approximately 1 mile west of the lightly treated area and 6 miles south of the heavily treated area. These

blocks were more nearly comparable to the areas that had been sprayed. However, since it was suggested that the records would be of greater value if taken fairly close to the sprayed areas and in several directions instead of in a solid block, beginning on July 26, fields at least 1 mile but not over 2 miles distant and situated on three sides of each treated area were used.

Samples were taken once a week except between August 7 and 12. The number of fields dipped each week depended on the amount of flooding in progress at the time, ranging between 10 and 16 per area with a general average of 14. Most of the dips in the sprayed plots were made close to the middle square mile, but stations were also established within half a mile of the edges to determine whether reductions were any greater near the center than approaching the border. Prior to July 14, 10 dips were made per field. On this date the number was raised to 20 and on August 16 was further increased to 30.

Early in the growing season the populations of *Anopheles* larvae were usually heaviest near the levees, but when the rice became tall enough to offer greater protection they were easily found throughout all parts of the field. However, in this investigation all the counts used are based on dips made while walking from 100 to 200 yards along the levees in both treated and untreated areas.

Around Stuttgart there is such a wide expanse of water surface available on which eggs can be laid that larval counts per dip, even when control measures are not applied, are generally lower than in certain other sections of this country where *Anopheles* mosquitoes are abundant. During the latter part of June and in July the weather was extremely hot (102° to 110° F. maximum) and dry, and there was a gradual decline in the numbers found in all fields. Throughout August frequent rains occurred and the weather was much cooler. A large increase in the population was observed during the middle of that month, and it continued to increase each week thereafter until the fields were finally drained.

Larvae were found in fields close to buildings and also distant from them. On one occasion four were collected at least three-fourths of a mile from the nearest sprayed resting place. This observation may indicate that adult *Anopheles* mosquitoes find other hiding places than wooden and metal structures and hollow trees, or that the adults fly long distances to deposit eggs.

The conclusions that have been drawn from this portion of the work are based on more than 11,000 dips. The results obtained each week are summarized in table 4. It has appeared likely, since the counts of the first week were made, that both treatments were causing a high degree of reduction, but not total elimination, of larvae, for fewer insects were always found in both treated areas than in either of the two untreated areas for the corresponding week. If the counts recorded in the untreated plots are indicative of the numbers that would have been found in the treated areas had no control measures been used, these DDT residues killed enough adult mosquitoes throughout the season to cause a larval reduction of 58 per cent.

The heavy deposit appears to have been slightly more efficient than the light deposit. On the basis of the first nine series of weekly observations, during which time all areas were being sampled, the average number of larvae collected per dip was 0.18 in the heavily treated area, and 0.16 in the lightly treated area, a difference of 17 per cent. Averages of 0.48 and 0.38 larva per dip obtained in the areas where no control measures were employed indicate a reduction of 63 per cent in the heavily treated area and 57 per cent in the lightly treated one. The two extra weeks of dipping reduced to 51 per cent the control caused by the light deposit.

Throughout June and July, when the larval population was at a comparatively low level, reductions of 73 per cent in the heavily treated area and 59 per cent in the more lightly treated area were indicated. It is probable, therefore, that aging of the residues and the tremendous larval increase that occurred during the latter part of the season reduced the degree of protection slightly.

SUMMARY.—DDT residual sprays were applied to the inside walls and ceilings of nearly every building in two 9-square-mile areas near Stuttgart, Ark., to determine the duration of effectiveness against *Anopheles quadrimaculatus* Say of a single application and to ascertain whether the general population of this species could be

Table 4.—Counts of *Anopheles* larvae obtained in two areas treated with DDT and in untreated areas nearby.

Date		Number of Dips		Total Larvae: Small		Medium		Large		Average Larvae per Dip		Per Cent Reduction
		Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	Treated	Untreated	
Treated area sprayed at 56 mg. per square foot												
June	21–22	141	120	8	57	12	11	11	3	0.22	0.59	63
	27–28	134	135	19	49	35	34	2	5	.4	.65	38
July	5– 6	140	100	11	8	4	17	2	5	.12	.3	60
	11–12	300	260	35	47	17	24	5	10	.19	.31	39
	17–18	220	200	2	8	0	21	1	3	.01	.16	94
	25–26	320	260	1	33	0	10	1	3	.01	.18	94
July 31–Aug. 1		320	260	3	26	3	4	2	2	.03	.12	75
Aug.	14–15	451	450	34	145	15	18	7	8	.12	.38	68
	21–22	450	480	95	223	50	58	27	36	.34	.66	48
	28	450	450	259	310	44	87	26	23	.75	.98	22
September	5– 6	420	390	305	549	89	274	15	52	.97	2.24	57
		3346	3105	772	1453	247	558	99	148	0.29	0.59	51
Treated area sprayed at 208 mg. per square foot												
June	20–23	140	140	49	91	18	22	1	8	0.49	0.86	43
	29–30	151	120	13	90	10	26	3	8	.17	1.03	83
July	7– 8	140	130	8	35	10	6	3	2	.15	.33	55
	13–14	280	250	5	56	6	18	2	9	.05	.33	85
	20–21	300	260	1	9	1	7	2	7	.01	.09	89
	27–29	320	280	1	18	5	20	0	3	.02	.15	87
August	2– 3	320	320	4	18	8	19	4	2	.05	.12	58
	16–17	480	450	75	276	30	36	9	19	.24	.74	68
	22–23	480	420	117	228	60	41	15	16	.4	.68	41
Total or average		2611	2370	273	821	148	195	39	74	0.18	0.48	63

reduced by using this method of control. One area was sprayed at the rate of 208 mg. of DDT per square foot and the other at the rate of 56 mg. per square foot. The degree of control was determined by comparing the numbers of mosquitoes found in the treated areas with those occurring in similar areas that were not sprayed.

Ten afternoon counts were made in these buildings between June and October, the last count 3.5 to 4.5 months after the sprays had been applied. The records showed that the residues had reduced the number of mosquitoes resting in the heavily treated buildings over 99 per cent and in the lightly treated buildings 91 per cent, throughout the entire season. More adults were found early in the morning than in the afternoon, but a high degree of reduction was also observed at that time.

Larval counts made in rice fields indicated reductions of 63 and 57 per cent, respectively, in the heavily and lightly treated areas. When untreated nail kegs were employed to sample the adult population, the results were too erratic to give a true index of the relative numbers present.—1-31-45.

Notice: Published Proceedings, Southern War Conference on Entomology

The proceedings of the First Southern War Conference on Entomology are available in mimeographed form. These include excellent symposia on the following subjects: Cotton Insect Control; Control of Pests Affecting Health and Comfort of Man and Domestic Animals; Fruit Insect Control; Insecticides and Machinery; Control of Pests of Commercial Vegetables and Victory Gardens; Control of Pests of Field Crops and Stored Products.

The proceedings include also the address of the President of the American Association of Economic Entomologists and technical papers. Copies may be obtained for $1.25 each from John T. Creighton, College of Agriculture, Gainesville, Fla.

Federal Quarantines Revised

The Japanese beetle quarantine and regulations were revised effective February 17, 1945, principally to bring within the regulated area certain election districts in Allegany and Charles Counties, Md., the cities of Olean, N. Y., and Ashtabula, Conneaut, and Marietta, Ohio, as well as Washington township in Lucas County, Ohio. The heavily infested area was extended to include additional township in 6 Pennsylvania counties, all of Nassau County, N. Y., and 2 towns in Suffolk County, N. Y.

The list of species of mahonia and barberry which are permitted to s shipped into the 18 states protected from the black stem rust under the provisions of Quarantine No. 38 has been revised to include *Mahonia dictyota*, M. *gracilis*, and M. *pinnata* (B.E.P.Q. 385, 4th revision, revised effective January 24, 1945).

DDT as a Residual-Type Treatment to Control *Anopheles quadrimaculatus*:[1] Practical Tests

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In tests at the Orlando, Fla., Laboratory of the Bureau of Entomology and Plant Quarantine in the spring and summer of 1943, DDT (2,2-bis (*p*-chlorophenyl)-1,1,1-trichloroethane) was shown to be highly effective against adult mosquitoes when applied as a residual-type spray to either wooden or canvas cages in the laboratory (Gahan *et al.* p. 236). The potentialities of DDT residues as a means of controlling malaria were discussed. However, additional tests, herein reported, were made in 1943, to ascertain whether this method of control is effective under more natural conditions.

A small room in which laboratory-reared adults of *Anopheles quadrimaculatus* Say were placed from time to time was used in the first test to be described. Most of the tests, however, were conducted in buildings near Tallahassee, Fla., and Stuttgart, Ark., that contained natural infestations of this species. Wherever possible a building in the same vicinity was left untreated for use as a check to observe increases or decreases in the normal population.

In most cases all exposed surfaces on the interior walls and ceilings of the buildings were coated with DDT, but in several tests partial treatment was used to find out whether thorough spraying was necessary to obtain complete control. No attempt was made to predetermine the amount of material to be applied. However, in many of the tests the output of the sprayer per minute or the amount of liquid used was calculated to ascertain the dosage of DDT applied.

TEST IN SMALL LABORATORY ROOMS.—A simulated practical test was made by spraying DDT in a kerosene solution onto the plaster walls of a small bathroom and confining from 25 to 50 laboratory-reared *Anopheles* adults in the room on the 3rd, 12th, 16th, 34th, 41st, 48th, 62nd, 69th, 84th, 98th, and 100th days after spraying. A dosage of 50 mg. of DDT per square foot was used on 160 square feet of surface.

All the insects died within 24 hours up to the 98th day. When less than 100 per cent mortality was again obtained on the 100th day, testing was discontinued. It is probable, however, that partial protection could have been obtained over a longer period, because 96 per cent mortality was obtained on both the 98th and 100th days.

The time required to knock down all insects gradually increased with the passage of time after application. On the 3rd day complete knockdown was obtained within 1 hour, but on the 12th and 26th days the time increased to approximately 3 hours. On the 69th day 26 per cent were resting on the walls or flying in the room at the end of 8 hours.

This room was also used to determine whether mosquitoes that have been exposed in DDT-treated rooms stop biting before they are actually incapacitated. Twenty-six days after it was sprayed 800 adults were released in the room, and a man was exposed at intervals of 10 to 15 minutes for periods of 3 to 10 minutes. The host had removed his clothing above the waist, and his trousers were rolled to the knees.

Some mosquitoes continued to bite until most of the lot were no longer able to fly. The biting rate at first was 3.6 per minute, and it was as high as 1 per minute when a knock-down of approximately 88 per cent had occurred 1 hour and 12 minutes after the insects were introduced. Occasional bites were still being received after 2.5 hours' exposure, at which time only 1 per cent of the insects were able to fly. It is apparent, therefore, that this type of residue will not necessarily prevent mosquitoes from biting when they enter a treated room.

TESTS IN BUILDINGS.—During August 1943 tests were made near Tallahassee, Fla., in 10 buildings situated in the vicinity of a small lake and a large swamp that annually breed mosquitoes. These build-

[1] This work was conducted under a transfer of funds, recommended by the Committee on Medical Research, from the Office of Scientific Research and Development to the Bureau of Entomology and Plant Quarantine.

[2] The authors are indebted to John E. Taylor, of the U. S. Public Health Service, for supplying the men and equipment used in spraying the buildings near Stuttgart, Ark.

ings included 6 privies, 2 animal sheds, a stable, and a single room in an abandoned house. Two barns and another room in the abandoned house, which were not sprayed were used as checks.

A kerosene solution and a water emulsion of DDT were used as sprays. Applications were made with a hand-operated compressed-air sprayer, to give deposits of 68 to 225 mg. of DDT per square foot of surface area.

One privy in which a water emulsion was used at the rate of 175 mg. of DDT per square foot and a shed treated with a kerosene solution at 65 mg. per square foot were sprayed only in the corners. All others were sprayed completely. The number of mosquitoes in these buildings before being treated usually ranged between 50 and 300.

Since Tallahassee is about 250 miles from Orlando, and these tests were conducted concurrently with laboratory tests, observations were not made frequently or at definite intervals. Several trips were made, however, before the end of the mosquito season to determine the results that were being obtained. Four buildings were observed over approximately a 70-day period, but the others were examined a single time, 6 weeks after the treatment. Since it is generally believed that most *Anopheles quadrimaculatus* adults enter buildings about dawn to rest during the daylight hours, and DDT residues do not kill rapidly, observations were made during the afternoon to record the maximum control that might be expected. After October 23 the weather became cold; checking was therefore discontinued until the mosquito season of 1944.

As shown in table 1, an impressive reduction in the number of mosquitoes remaining in the treated buildings has occurred so far in these tests. Although complete absence of adults was not always attained, the numbers counted after treatment were consistently much lower than those observed prior to spraying and in untreated buildings used as checks. In two of the four buildings that were checked at intervals over a 70-day period, live mosquitoes were never seen when examinations were made in the afternoon. A privy that had been completely treated with a deposit of 175 mg. per square foot was free from mosquitoes on the 13th and 29th days, but two adults, one obviously affected, were found on the treated walls on the 69th day.

Table 1.—Residual toxicity of DDT when applied to the walls and ceilings of buildings in the vicinity of Tallahassee, Fla.

Number of Buildings		Time of Observation	Average Number of Live Mosquitoes per Building	
Treated	Untreated		Treated	Untreated
4	2	Before spraying	86	45
		After spraying:		
		2 weeks	0	57
		4 weeks	.3	58
		10 weeks	4	13
6	1	Before spraying	207	625
		6 weeks after	3	54

The treatment that appeared to be the least effective was an application of 90 mg. of DDT per square foot to an old shed partially lined with paper, in which spiders had constructed numerous webs. As early as the 29th day 1 adult mosquito was observed in the building, and on the 70th day 9 were found, 4 of which were seriously affected. Three of the mosquitoes that appeared to be unaffected were resting on spider webs. Since spider webs appear to provide favorable resting places for *Anopheles quadrimaculatus* adults and the presence of newly constructed webs may reduce the efficiency of DDT residues, it seems desirable to keep treated buildings free of them.

Four of the buildings, including the partially treated privy, that were examined only 6 weeks after being treated were free of mosquitoes, but, live adults were found in the other 2. Four badly affected mosquitoes and 2 that appeared to be in good condition were noticed in a privy completely treated with a kerosene solution at a dosage of 148 mg. of DDT per square foot. The shed that had been sprayed in the corners at the rate of 65 mg. per square foot contained 11 mosquitoes, 6 of which were obviously affected.

Fifty dead mosquitoes were once found on a spider web in a treated privy, but in most of the sprayed rooms they were seen only occasionally. Although a laboratory test had indicated that DDT was not highly repellent, the absence of dead insects suggested that mosquitoes might not be contacting these residues, but were being repelled to other resting stations. However, when nine of the buildings that had been treated at least 39 days previ-

ously were examined immediately after sunrise, live mosquitoes were found resting on the walls in all of them. The numbers ranged between 12 and 66.

One of these buildings was observed for 2 hours after sunrise, and several mosquitoes were seen flying out of the open windows, confirming laboratory observations that DDT activates these insects. Since it was believed possible that mosquitoes might have left before they had obtained a toxic dose, several tests were made in a room that had been treated 70 days previously with 68 mg. of DDT per square foot, in order to find out whether those mosquitoes that escaped from treated buildings will die within 24 hours.

On one occasion the windows and doors were closed at about 8 a.m., trapping 66 adults that had voluntarily entered. As they became activated and flew against the windows, they were caught in glass vials and transferred to an untreated holding cage. All but two mosquitoes tried to escape within 4 hours. Ninety-five per cent of those that came to the windows were either dead or knocked down 24 hours later. Two similar tests were made by turning loose in the same room adults that had been collected in untreated privies and sheds. Mosquitoes began flying against the windows within 5 minutes after they were introduced, and during the first 2 hours a total of 135 were captured in the 2 tests. Eighty-nine per cent of them died within 24 hours. Every survivor was a female, but over 70 per cent of the females were killed in each of these three tests. It is highly probable, therefore, that most *Anopheles quadrimaculatus* adults escaping from buildings treated with DDT live less than 24 hours.

TESTS IN BUILDINGS NEAR STUTTGART.—Stuttgart, Ark., is located in an important rice-producing area, where cultural practices are responsible for the production of tremendous numbers of mosquitoes. Rice is seeded in the spring, levees are constructed on contours, and fields are flooded with water pumped from a main ditch. During the summer *Anopheles quadrimaculatus* and *Psorophora* spp. breed in these fields and in numerous bayous found in the vicinity, as well as in permanent pools that form in the roadside ditches adjacent to the fields.

In this area tests were conducted in a shed, a milk house, a feed room, a galvanized-metal pump house, a privy, and 12 buildings or enclosures used for housing animals. All the surfaces were unpainted, with the exception of those in the milk house and two chicken houses, which were whitewashed. The numbers of *Anopheles* adults found in the various buildings before spraying frequently were as high as 200 to 1000, and in one feed room there were approximately 5000. Nine untreated buildings, including 3 barns, 2 sheds, a granary, a chicken house, a hog house, and a mule barn, that were located close to at least one of the treatments were used as checks.

Three types of sprays were used—Water emulsions, water suspensions, and kerosene solutions.

The applications were made during the last week of August 1934, by employees of the Arkansas State Board of Health and the U. S. Public Health Service under the direction of the authors. A 50-gallon power sprayer having an adjustable nozzle and a hand-operated rotary duster were used to dispense the DDT.

Complete coverage of all interior walls and ceilings was made in every test but two. The south half of one barn was sprayed but not the north half. Another barn was treated only on the west side of the exterior, where approximately 700 mosquitoes were found resting. The rate of application was not determined for every treatment, but in 10 spray tests the deposit was calculated. By varying the percentage of DDT in the mixture dosages ranging from 76 to 400 mg. per square foot of surface were applied.

The buildings were examined about once a week by L. H. Biggs, of the U. S. Public Health Service. The results are shown in table 2. Mosquitoes present at the time of spraying were knocked down within a few minutes. Seven of the buildings that had been completely sprayed, the barn that had been sprayed on the west wall, and one of the three that had been dusted, were still free of mosquitoes 7 weeks following treatment. In open buildings few dead mosquitoes were found but in rooms that had only one or two exits hundreds were found on the floor.

In other tests the following deposits per square foot were obtained on buildings completely sprayed with DDT: A feed room 127 mg., a chicken house 84 mg., a barn 76 mg. A hog house and a galvanized

Table 2.—Residual toxicity of DDT when applied to the walls and ceilings of buildings in the vicinity of Stuttgart, Ark.

Time of Observation	Average Number of Live Mosquitoes per Building	
	17 Treated Buildings	9 Untreated Buildings
Before spraying	357	297
Weeks after spraying:		
1	8	273
2	10	154
3	4	108
4	2	52
5	1	9
6	.4	7
7	.2	4

metal pump house were completely sprayed at an undetermined rate, a barn was partially sprayed to give a deposit of 158 mg. of DDT per square foot, and a barn and a chicken house were completely dusted with a 25 per cent DDT-talc mixture. Although complete protection was not obtained, an impressive reduction in the number of live mosquitoes occurred in all structures except the galvanized-metal pump house. For example, the feed room had an estimated population of 5000 mosquitoes prior to treatment, but only 62 insects were counted 1 week later and nine after 2 weeks. The number observed in the barn that had been completely sprayed had decreased from 1000 to 20 upon examination after 1 week. The treatments were equally effective in the other tests.

In the galvanized-metal pump house, although the population was reduced considerably during the first week, by the 9th day the number of live mosquitoes observed was two-thirds as great as the infestation immediately prior to spraying. The spray did not adhere to the metal and much of it ran off, which may account for the poor results.

Most of these examinations were made during the morning hours. Had they been made in the afternoon, probably fewer insects would have been present, owing to the additional exposure time.

Counts made in untreated buildings nearby indicate that the DDT residues in the treated buildings may have reduced the mosquitoes present in the surrounding area, for a steady decline was noticed in the numbers. There was also a marked reduction on the untreated walls in the barn that had been only partially sprayed. However, these sprays were not applied until the latter part of August, by which time most of the water had been drained from the rice fields and mosquitoes normally begin to disappear. For this reason no definite significance can be claimed for this observation at present.

PRACTICAL TEST AGAINST *Psorophora*.—A test of the effectiveness of DDT residues against *Psorophora* spp., mosquitoes not considered as disease carriers, was made near Stuttgart. Three walls of a dairy barn were treated with the previously mentioned water suspension containing 1 per cent of DDT. The doors at opposite ends of the barn were left open, and a 40-watt light bulb was lighted at night to attract mosquitoes into the building. After being attracted to the light, they roosted on the treated walls. The following morning many dead mosquitoes were seen on the floor. The light was burned again that night, and the next morning approximately 50,000 dead *Psorophora* were found on the floor. It is probable that many others flew out of the open doors and died elsewhere.

DISCUSSION.—The tests reported in this paper show that DDT can be used effectively as a residual-type treatment against mosquitoes when applied to surfaces where they rest. Since the treatments were made late in the season, no definite statement can yet be made regarding the frequency of applications necessary to obtain satisfactory results. The results obtained thus far, however, indicate that one or two thorough sprayings a season may prove sufficient to keep buildings relatively free of *Anopheles quadrimaculatus*. The data obtained on partial spraying of buildings are inconclusive, and additional tests will be required to evaluate this type of application.

It is possible that DDT spray residues do not act rapidly enough to eliminate all annoyance caused by the mosquitoes that enter homes. However, on the basis of these results it is believed that the chemical will prove a valuable replacement for, or supplement to, other methods of killing adult mosquitoes to reduce the spread of malaria and other mosquito-borne diseases.

At the present time military camps are frequently treated with pyrethrum sprays. Weekly applications of pyrethrum sprays

have been shown to protect huts in India from mosquitoes for only 1 to 3 days (Russell & Knipe 1941) and in South Africa the more frequently huts were sprayed the lower was the rate of malaria and the fewer were the infected anophelines per building (De Meillon 1936). If, as has been shown by several investigators, these methods of killing adult mosquitoes in buildings are effective in controlling malaria, DDT residues probably will accomplish the same purpose more efficiently and with less labor. One application of a DDT spray should continue to kill for indefinite periods most of the domestic species of mosquitoes that attempt to rest in treated buildings. Total mortality may be expected if the structures are tight enough to prevent the pests from leaving readily, and a high percentage of control should result even in places where mosquitoes can easily escape.

In many of the malarious areas our troops are encamped near villages where the natives are living in more or less open quarters and the incidence of malaria is very high. Soldiers frequenting such villages are exposed to the anophelines that having fed on these hosts. Spraying the interior of the huts a single time with DDT might reduce the number of infected mosquitoes for long periods, thereby reducing the disease incidence among the natives and greatly lessening the danger of our troops contracting the disease.

Heretofore insecticides used to control mosquitoes in buildings have been sprayed into the air rather than on stationary objects. DDT, however, should be applied directly onto the walls and ceilings. A coarse spray is preferable to a mist, for with fine atomization a large portion of the chemical will eventually reach the floor and be wasted. Fogging the air is unnecesasry, and the solvents in the spray formulas used so far will cause discomfort to the operator unless he wears a respirator. Treatment with DDT may be considered a painting operation. Dusts have also been found effective.

SUMMARY.—In practical tests conducted near Tallahassee, Fla., and Stuttgart, Ark., DDT applied in various carriers at dosages ranging from 65 to 400 mg. per square foot has been found to protect buildings from natural infestations of *Anopheles quadrimaculatus* Say adults as long as 70 days. Complete elimination was obtained with a high percentage of the treatments. When mosquitoes were present in the treated buildings, the number was always much lower than prior to spraying or in untreated buildings used as checks. The chemical activated the mosquitoes and caused many of them to leave the building, but a large percentage of those that escaped had obtained a lethal dose. In one test numerous *Psorophora* adults were killed when a light was used to attract them to a treated building.

In a simulated practical test 100 per cent mortality was obtained over an 84-day period when laboratory-reared *Anopheles quadrimaculatus* adults were confined in a terated room for 24 hours. On one occasion, however, some mosquitoes continued to bite a host exposed in this room until a knockdown of 99 per cent had occurred.—1-31-45.

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DDT as a Residual-Type Spray to Control Disease-Carrying Mosquitoes:[1] Laboratory Tests

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In certain theaters of the present war the casualties caused by malaria are reported to exceed by far those caused by the enemy. If this scourge could be eradicated for our armed forces, our final victory could be realized with fewer men and in shorter time. Research conducted at the Orlando, Fla., laboratory of the Bureau of Entomology and Plant Quarantine has demonstrated a new approach to the control of the many anopheline mosquitoes that rest in buildings.

Good control of malaria mosquitoes by spraying entire villages once or twice a week with pyrethrum has been reported by various investigators in Africa (Thornton 1933–35, DeMeillon 1936, Ross 1936) and India (Covell *et al.* 1938, Russell & Knipe 1939–41). In India the disease was practically eliminated in 3 years by weekly sprayings during the malarial season. Other investigators have obtained similar results. The spraying of buildings with pyrethrum is also being used to control malaria around army camps. Pyrethrum sprays at the concentrations used, however, seem to lose their effectiveness, and frequent applications are necessary. A chemical having a long-lasting residual toxicity that could be sprayed on the walls and ceilings of buildings would be more desirable. Such a chemical should leave a residue that would be continuously active in killing the mosquitoes that rested on it.

In April 1943 preliminary tests were made to determine the effectiveness of DDT (2,2-bis (*p*-chlorophenyl)-1,1,1-trichloroethane) residues against mosquitoes. Similar studies against bedbugs and flies were under way by several associates at the Orlando laboratory. Within a few days it was apparent that this chemical deposit offered much promise as a means of controlling mosquitoes. A large series of laboratory tests with treated cages were immediately started, using adult *Anopheles quadrimaculatus* Say and *Aëdes aegypti* (L.), to determine the practicability of this control method. Several months later it was discovered that Wiesmann (1943) had found DDT residues effective against adult flies infesting stables.

MATERIALS AND METHODS.—The mosquitoes were exposed in treated cages having a surface area of about 2.4 square feet. Two types of cages were used, canvas and wooden. Cylindrical canvas cages were formed by reinforcing pieces of canvas on the outside with wire screen and fastening two opposite sides of the canvas together with a zipper. In one end a glass beaker was inserted to serve as a window, and at the other end the edges of the canvas were folded together and fastened with a rubber band. The wooden cages were boxes with the sides made of cypress wood, a wire screen at one end, and a cloth sleeve at the other.

During treatment and when not being used in tests, the cages were dismantled and hung flat on racks, with the treated surface exposed to the air. All sprays were applied to the surface on one side with a DeVilbiss atomizer.

In most of the tests mosquitoes were introduced into the assembled cages on the first and fourth weeks after spraying and every fourth week thereafter until testing was discontinued. A test was terminated when in two consecutive trials the treatment failed to kill all the insects in 24 hours. The knock-down was recorded hourly for the first 5 hours, and at 15-minute intervals during the first hour with treatments that gave quick action. Mortality counts were made after 24 hours. In these tests mosquitoes were confined continuously in the cages for the 24-hour period. Only a few cages have failed to give 100 per cent mortality after 200 days. Since most residue treatments are still completely effective at the time this paper is being written (March 1944), it has been necessary to judge their relative values by the rapidity of knock-down.

To determine the length of time mos-

[1] This work was conducted under a transfer of funds, recommended by the Committee on Medical Research, from the Office of Scientific Research and Development to the Bureau of Entomology and Plant Quarantine.

[2] The authors wish to thank E. F. Knipling and H. A. Jones for their technical assistance in the conduct of this work.

quitoes must remain in contact with a DDT residue to obtain a lethal dose, a second type of exposure was made in which mosquitoes were confined in cages for intervals ranging between 15 minutes and 4 hours and then transferred to untreated screen holding cages. The mortality after 24 hours was used to evaluate the treatments. All cages in this series were tested 7 days after treatment and subsequently at 4-week intervals.

In many of the tests only one cage was used, although a number of treatments were applied to both a wooden box and a canvas cage. The number of insects used per test varied, but averaged 29. The data given in most of the tables are averages for the observations made over the entire period of the tests.

RELATIVE SUSCEPTIBILITY OF SPECIES.—In the early 24-hour exposure tests adults of both *Anopheles quadrimaculatus* and *Aëdes aegypti* were used. It soon became apparent that there was no great difference in susceptibility between these two species, although *A. aegypti* was usually knocked down slightly faster. An example of the results obtained is given in table 1. *A. aegypti* was therefore eliminated as a test insect, and the discussions to follow are based entirely on the results obtained against *A. quadrimaculatus*.

Table 1.—Comparative susceptibility of *Anopheles quadrimaculatus* and *Aedes aegypti* adults to deposits of DDT applied in a 1 per cent water suspension at a dosage of 50 mg. of DDT per square foot. Average of 5 tests over 6-week period.

Species	Per Cent Knock-down in—					Per Cent Kill in 24 Hours
	1 Hr.	2 Hrs.	3 Hrs.	4 Hrs.	5 Hrs.	
Tests in wooden cage						
Aëdes aegypti	9	26	65	86	95	100
Anopheles quadrimaculatus	2	30	46	69	75	100
Tests in canvas cage						
Aëdes aegypti	21	92	95	100	100	100
Anopheles quadrimaculatus	30	82	92	97	99	100

EFFECT OF VARYING THE CONCENTRATION OF DDT.—Wooden boxes and canvas cages were sprayed with 4, 2.5, 2, and 1 per cent solutions of DDT in kerosene to obtain deposits of 50 mg. of DDT per square foot. The results indicated that the concentration of chemical in the spray does not materially affect the toxicity of the residue if the deposit is the same. However, 2.5 per cent of DDT was found to give good coverage on the test cages, and has been used in all the subsequent tests except the one with a water suspension, which contained only 1 per cent.

EFFECT OF VARYING THE CARRIER.—The carrier used in applying a deposit of this type is an important consideration, since the insecticide must remain on the surface of the wood or canvas to contact the insects. A solvent that has a low boiling point and does not soak into the treated surface should be the most satisfactory. A series of comparative tests were made with sprays containing DDT applied in various solvents having a wide range of boiling points and in a water emulsion and a water suspension. Applications were made at the rate of 50 mg. of DDT per square foot of surface, and most of the treatments were tested over a 32-week period.

Although the results indicated that the carrier is an important consideration, emphasis is being placed on the development of kerosene solutions and water sprays because they can be made available in sufficient quantities for the armed forces. The water emulsion and the suspension that has been used most extensively leaves a visible deposit on some painted or varnished woods, whereas residues from kerosene solutions are practically invisible. These visible deposits would be satisfactory for use in rough buildings, but would be unsightly in buildings with finished interiors and varnished furniture. However, a number of other water emulsions have been sprayed at the rate of 200 mg. of DDT per square foot on small sections of varnished board that had received two coats of varnish 2 weeks previously, and some of the residues were found to be invisible or only slightly visible.

In tests to compare the effectiveness of emulsions, suspensions, and solutions, sprays were applied to wooden boxes at various dosages, and mosquitoes were exposed to the residues for 24-hour periods. The results (Table 2) show that all treatments were completely effective throughout the 16-week period of the experiment. Increasing the dosage from 50 to 400 mg. per square foot shortened the time required to knock down very slightly, but not enough to justify the heavier deposit. The emulsion and the suspension ap-

Table 2.—Toxicity of DDT residues to *Anopheles quadrimaculatus* adults exposed continuously and for short periods in wooden boxes sprayed with various dosages of DDT in a water emulsion, a water suspension, and a kerosene solution. Average of 5 tests over 16- to 17-week period.

Type of Treatment	Dosage of DDT, Mg. per Sq. Ft.	Continuous Exposure: Per Cent Knock-down in— 1 Hour	2 Hours	3 Hours	4 Hours	5 Hours	Per Cent Kill in 24 Hours	Short Exposures: Per Cent Mortality 24 Hours After Exposure of— ½ Hour	¾ Hour	1 Hour	2 Hours	4 Hours
Water emulsion	50	10	48	93	97	99	100	30	45	63	78	92
	100	21	63	98	99	100	100	32	55	79	96	99
	200	23	71	96	98	100	100	46	65	86	89	100
	400	21	68	99	99	99	100	45	59	84	94	100
Water suspension	50	5	56	92	98	98	100	39	47	66	86	96
	100	9	67	96	100	100	100	36	63	60	90	99
	200	6	68	96	100	100	100	40	63	67	93	96
	400	8	77	97	100	100	100	44	55	69	88	95
Kerosene solution	50	6	45	70	82	92	100	29	41	37	61	92
	100	7	55	85	94	98	100	29	42	54	75	89
	200	16	64	97	100	99	100	46	56	77	92	100
	400	10	76	96	98	100	100	36	67	63	85	100

peared to be equally effective, and both were slightly superior to the kerosene sprays at dosages of 50 and 100 mg. per square foot.

When mosquitoes were confined in the treated cages for intervals of 0.25, 0.5, 1, 2, and 4 hours instead of 24 hours, the results in general corroborate the findings in the 24-hour continuous-exposure tests.

Time Required to Obtain Lethal Dose.—It may be seen from table 2 that a long exposure period was required before all the mosquitoes obtained a lethal dose. No accurate record was obtained of the actual time of contact with the chemical, because the insects spent a large part of their time flying in the boxes. Exposures of 2 to 4 hours were required to give kills approaching 100 per cent with treatments that had been applied no longer than 1 week, and in some cases a lethal dose was not obtained after 4 hours. The exposure time required for complete mortality was the same 17 weeks after the sprays had been applied, and increasing the amount of DDT from 50 to 400 mg. per square foot did not materially decrease the time.

Duration on Unpainted Surfaces.—The first box sprayed with DDT was an unpainted wooden packing box. This box, treated with 50 mg. of DDT per square foot, caused complete mortality in every test, including the last, 1 year after application.

When applied to unpainted wood and canvas at the same dosage, DDT in emulsion, suspension, and certain solutions was still causing 100 per cent mortality after 32 weeks. A dosage as low as 10 mg. of DDT per square foot, in a kerosene solution, was still completely effective on canvas after 32 weeks, but on wood it failed to kill all insects on one occasion over a similar period, 98 per cent being knocked down the 24th week. However, all treatments were slowly losing their effectiveness, because the time required to knock down the insects gradually increased. This point is illustrated by the results obtained with a 50-mg. dosage of DDT applied to a canvas cage (Table 3).

Table 3.—Toxicity of DDT to *Anopheles quadrimaculatus* adults at various intervals after treatment when applied in a kerosene solution to a canvas cage.

Weeks After Spraying	Per Cent Knock-down in— 1 Hr.	2 Hrs.	3 Hrs.	4 Hrs.	5 Hrs.	Per Cent Kill in 24 Hours
1	27	100	100	100	100	100
4	5	84	100	100	100	100
8	34	94	97	100	100	100
12	31	86	92	96	98	100
16	12	79	90	94	86	100
20	0	45	48	55	55	100
24	8	25	39	53	97	100
28	4	38	42	94	98	100
32	0	16	84	94	94	100

For comparative purposes the residual effectiveness of pyrethrum was also determined by spraying a wooden box and a canvas cage with this well-known insecticide. In contrast to DDT, 50 mg. of pyrethrins applied in a kerosene solution failed to give complete control after the sixth week on both wooden and canvas surfaces. The box failed the first week, at which time 94 per cent were knocked down, but prostrated all mosquitoes on the second, third, fourth, and fifth weeks.

After the first week these residues acted no faster than DDT. Tests were made with these cages at weekly intervals.

DURATION ON PAINTED SURFACES.—DDT has been found highly effective when applied to surfaces coated with a cold water-casein paint. Thirty-two weeks after a 50-mg. dosage had been applied in an emulsion and a kerosene solution to wooden boxes, both boxes were still killing all mosquitoes. However, when these sprays were applied on boxes that had been given two coats of oil paint less than 2 seeks previously, mortalities below 100 per cent were obtained 1 week after treatment, and the knock-down observed during the first 5 hours was under 25 per cent. It appeared that the solvents may have softened the paint enough to affect the chemical in such a way as to make it unavailable to the insects.

EFFECT OF LIGHT ON DDT RESIDUES.—Three boxes and three canvas cages that had been sprayed with kerosene solutions at 50 mg. of DDT per square foot were used to determine the effect of light on this chemical. Except while being used in tests and on rainy days, one box and one canvas cage were hung outdoors in the sun during the daylight hours. A second pair was retained in a laboratory room, while a third pair was placed in a dark closet.

Sunlight had a deleterious effect on the residue, for a longer exposure was required to knock-down mosquitoes in the box and cage placed outdoors than in those kept inside, but the loss in toxicity was slow. All three cages and the two boxes that were kept in the laboratory room and the closet were still causing 100 per cent kill 40 weeks after treatment, but the box subjected to sunlight was completely effective only through the 24th week. Since *Anopheles* mosquitoes normally rest in dark places, any deleterious effect of sunlight may have little practical significance.

REPELLENCY TESTS.—Mosquitoes will rest on surfaces sprayed with DDT. It has been observed, however, that some time after they have been introduced into treated cages they begin to fly and often try to get out, whereas mosquitoes confined in check cages usually rest quietly. To ascertain whether DDT residues would repel mosquitoes before they obtained a toxic dose, six wooden boxes that had been sprayed for at least 40 days previously and an untreated box were placed in a 30-inch cubical cage containing approximately 200 anophelines. Fifteen minutes later 158 mosquitoes were observed resting on treated surfaces; 45 minutes later the count had decreased only to 120, and at the end of 3 hours 96 were still using treated boxes as a resting place. One hundred and fifty-two dead mosuqitoes (76 per cent) were counted 24 hours later. The population in the untreated box averaged approximately 37 during the first 6 hours of the test. It is therefore apparent that most of the mosquitoes that did not remain in the untreated box obtained a lethal dose in the treated boxes before they were repelled.

DISCUSSION.—DDT residues do not have a rapid knock-down action, as do pyrethrum sprays and aerosols. In the tests reported in this paper all mosquitoes were rarely prostrated in less than 1 or 2 hours, and often 5 hours or more were required. This characteristic of the chemical should not seriously affect its use as a control measure against malaria, however, for at least 10 days to 2 weeks must elapse between the time mosquitoes bite an infected host and the development of the plasmodia to the infective stage. If the treatment is effective under practical conditions and all buildings, tents, and other mosquito resting places near malarial patients are sprayed, most of the mosquitoes that remain in the vicinity of their blood meal should be killed before they become transmitters of the disease. Its slow action however, may permit insects that have already reached the infective stage to inoculate uninfected hosts and also will lessen its value in preventing annoyance.

DDT deposits will eventually lose their efficiency, as shown by a gradual increase in the time required to cause knock-down. In laboratory tests, however, they remained effective for as long as 52 weeks. In actual practice protection may be much shorter, because mosquitoes may be able to leave treated buildings readily and will rarely be exposed to the chemical continuously for 24 hours.

Not only do the experimental data show that pyrethrum sprays have some residual action, but it is believed that those who have used pyrethrum sprays for malaria control have received benefits from resi-

due as well as from direct contact. It is doubtful, however, whether this insecticide can be considered practical as a residue spray, because it is effective for shorter periods than DDT, the cost is too high, and it is not available in sufficient quantities.

SUMMARY.—In laboratory tests DDT has been found effective as a residual-type spray against adults of *Anopheles quadrimaculatus* Say and *Aëdes aegypti* (L.), when applied on wooden boxes and canvas cages at the rate of 10 to 400 mg. per square foot.

Comparative tests showed a water emulsion and a water suspension to be equally effective on wood, and both slightly superior to a kerosene spray. An exposure period of at least 2 to 4 hours was required before all mosquitoes obtained a lethal dose.

Many of the residues were still completely effective after 32 weeks when 24-hour exposures were used. Sunlight had a deleterious effect, but the loss in toxicity occurred very slowly, for a deposit of 50 mg. did not fail to kill mosquitoes until after the 24th week. DDT residues were highly toxic on unpainted surfaces and on surfaces covered with two coats of cold water-casein paint that had been applied less than 2 weeks. The residue was much less effective, however, on surfaces recently painted with oil paint.

The chemical activated the mosquitoes that rested on treated surfaces and caused the insects to fly, but not before most of them had obtained a lethal dose.—1-31-45.

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PHONY PEACH AND PEACH MOSAIC DISEASE QUARANTINES

Federal and State surveys and inspections for the phony peach and peach mosaic diseases were conducted in 1944 in 16 known infected States and in other states as time permitted. Inspections included all nurseries and their environs in infected areas, budwood sources and their environs in mosaic areas, and commercial and other peach plantings in areas and states where eradication is in progress. Standard state quarantines provide that regulations may be lifted as to any state or county on satisfactory evidence of a 3-year disease-free period. Under that provision 3 counties in Texas and 1 in Utah are eligible for release from the peach mosaic regulated area. The states maintaining phony peach quarantines can now release from the regulations 51 Louisiana parishes, 16 counties in Mississippi, 3 each in Tennessee and Texas, 2 in Missouri, and 1 in Illinois. The entire State of Illinois can now be freed from the requirements of the standard phony peach quarantines.

Peach mosaic was found for the first time in Alfalfa and Woods Counties, Okla., and San Juan County, New Mex. The phony peach disease was not found in any county outside the known infected areas.

The so-called blueberry "stunt" disease is the subject of Michigan Quarantine 606, which became effective September 1, 1944, requiring inspection for this disease in the case of all blueberry plants shipped to the State or moved within it.

The narcissus bulb fly, *Merodon equestris* Fab., is no longer placed under quarantine by the State of Oregon. The intrastate and interstate quarantines as re-issued, effective August 21, 1944, pertain only to the bulb nematode, *Ditylenchus dipsaci* Kuehn.

The fumigation of sweetpotatoes by methyl bromide is accepted by the State of Oklahoma as a condition of admissibility of the tubers from sweetpotato weevil infested areas. This provision, which became effective October 1, 1944, is set forth in Amendment No. 1 to the State quarantine Order (No. 2) as revised effective September 1, 1944.

DDT as an Anopheline Larvicide—Laboratory Tests[1]

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In testing synthetic organic compounds at the Orlando, Fla., laboratory of the Bureau of Entomology and Plant Quarantine to find a material suitable for use as a practical anopheline larvicide, it was discovered that DDT (2,2-bis(*p*-chlorophenyl)-1,1,1-trichloroethane) is extremely toxic to larvae of *Anopheles quadrimaculatus* Say. DDT is far more toxic to mosquito larvae than phenothiazine, which is one of the most toxic synthetic organics previously tested, and it also has a decided advantage over paris green in that it may be applied in a number of different ways.

The laboratory tests were designed to compare the toxicity of DDT and other mosquito larvicides and to study the various ways in which DDT might be used in the field—as in dusts, surface applications in oils, and in emulsions and suspensions. Field tests with this material are reported elsewhere.

PHYSICAL PROPERTIES.—The physical properties of DDT make it very adaptable for use as a larvicide. It is soluble in a wide range of organic solvents. Its solubility in the petroleum oils makes possible wide application in mosquito-control programs where larvicidal oils are now used.

DDT has a specific gravity of 1.6 and is practically insoluble in water. It is also nonwetting and therefore resistant to sinking by rains. When applied as a larvicide it appears to be stable chemically to the action of sunlight and water.

The melting point of the pure compound is 108° C. The melting point of the present commercial product is much lower, however. In fact it is so low that when the material is ground to a small particle size the resulting powder tends to clump together. The preparation of DDT dusts is therefore slightly more difficult than when paris green is used.

TESTING PROCEDURE.—In most of the tests early fourth instars of *Anopheles quadrimaculatus* were used, so that 24- and 48-hour mortality readings could be made before the larvae were ready to pupate. Such larvae would be actively feeding and likely to ingest any surface application, though no food was offered during the test period.

Although the larvae were reared in the laboratory, they varied in susceptibility from day to day, and even in different rearing pans from the same brood. To correct this variation larvae to be used in a given day's tests were transferred to large crystallizing dishes, and from this mixed population a random sample of 20 larvae was taken for each test. A standard of recrystallized DDT in acetone suspension was run in each series of tests as a check on day-to-day variation.

Dust applications were made by sifting a weighed dosage through a fine-mesh screen. Liquid doses were measured with a pipette.

The residual toxicity of surface applications at dosages that could be measured in the laboratory was so long lasting as to make the accumulation of data laborious and slow. Special techniques, such as "artificial rains," were therefore used to shorten the lasting period as well as to simulate field conditions.

White enamel pans 12 inches in diameter were used where no rain was given, and glass battery jars 6 inches in diameter in the "rain" tests. The jars were filled 1 inch deep with water, and after the application of larvicide an artificial rain of 6 inches was given in 4 to 5 minutes, the water falling in droplets a distance of 6 feet. By siphoning off the water repeated rains could be given without removing the surface film. A material was considered to have lost its residual effectiveness when the mortality after 48 hours was 80 per cent or less.

TOXICITY OF VARIOUS CONCENTRATIONS.—In acetone-water suspensions DDT gave an average mortality of 98.2 per cent at a concentration of 0.01 p.p.m. In 16 out of 22 replicates 100 per cent mortality was obtained, but in 1 test it was as low as 85 per cent. At 0.005 p.p.m.

[1] This work was conducted under a transfer of funds, recommended by the Committee on Medical Research, from the Office of Scientific Research and Development to the Bureau of Entomology and Plant Quarantine.

[2] Acknowledgment is made to E. F. Knipling, in charge of the Orlando, Fla., laboratory, for suggestions and criticisms, and to Donald K. Scharff, who reared the larvae used in these tests.

the average mortality was 55.5 per cent, and at 0.0025 p.p.m. it was 23.2 per cent. In this range, however, considerable variation in larval susceptibility was evident. Some toxicity was shown at 0.00125 p.p.m.

Variation in susceptibility on different days was such that minimum lethal-dosage determinations were indefinite and impractical.

COMPARATIVE TOXICITY OF DDT AND PHENOTHIAZINE.—A comparison of DDT and phenothiazine when applied as suspensions made from acetone solutions is given in table 1. DDT is shown to be more than 100 times as toxic as phenothiazine. Both compounds are nerve poisons and act more slowly than the arsenicals.

It is difficult to compare the rapidity of action of two materials so different in toxicity, but at concentrations that give approximately 100 per cent mortality the DDT acts more rapidly than phenothiazine.

Table 1.—Comparative toxicity of suspensions of DDT and phenothiazine to fourth instars of *Anopheles quadrimaculatus*. 5 replications.

MATERIAL	CONCENTRATION	AVERAGE MORTALITY AFTER 48 HOURS
	P.p.m.	*Per cent*
DDT	0.01	100
	.005	94
	.0025	55
Phenothiazine	1.0	79
	.1	10
	.05	7

COMPARATIVE TOXICITY OF DDT AND PARIS GREEN.—The only direct comparison that can be made between DDT and paris green is in dust applications. In table 2 these materials diluted in talc are compared at different rates of application.

It will be seen that a 0.1 per cent dust was completely effective at a dosage of 0.005 pound per acre. In practical use DDT can be used at a strength as low as 1 per cent without seriously impairing its efficiency, whereas such a large proportion of carrier is known to reduce the efficiency of paris green. Paris green is soluble in water and is readily sunk by rains, has a high specific gravity, and is insoluble in the organic solvents.

The effectiveness of paris green was greatly reduced after one artificial rain, whereas DDT, at a dosage of 1 pound per acre and in the same carrier, remained effective for 26 days and withstood 13 rains before the mortality after 48 hours was 80 per cent or lower.

Table 2.—Comparative toxicity of paris green and DDT when applied as dusts to fourth instars of *Anopheles quadrimaculatus*. 5 replications.

MATERIAL	CONCENTRATION OF ACTIVE INGREDIENT	DOSAGE OF ACTIVE INGREDIENT	AVERAGE MORTALITY IN 48 HOURS
	Per Cent	*Pound per Acre*	*Per Cent*
Paris green	5	0.1	85
		.05	76
		.025	49
		.01	12
DDT	0.1	.005	100
		.0025	95
		.0015	87
		.0001	62

APPLICATIONS IN DUSTS.—DDT dusts prepared by mechanical mixing with various diluents, particularly the waxy solid fatty acids, higher alcohols, and esters, were resistant to sinking due to rain. Solid solutions of DDT in these materials were especially resistant to sinking.

A solid solution containing 20 per cent of DDT in stearic acid was made into a dust which had a specific gravity almost equal to that of water. This type of preparation, however, did not mix well. Its dusting qualities were improved by mechanically mixing with a powder such as talc or calcium stearate.

A comparison was made of dusts containing 20 per cent of DDT in talc and in stearic acid. A dust application at 0.5 pound per acre was subjected to artificial rain on the day of application and on alternate days thereafter, and following each "rain" larvae were introduced into the jars. In 8 replications DDT in talc remained effective for an average of 30 days with 16 rains, and in 9 replications DDT in stearic acid was effective for 38 days with 20 rains.

When equal parts of calcium stearate and stearic acid solution of DDT were used, mortalities above 80 per cent were obtained for 86 days with 44 artificial rains.

The resistance to being sunk by the artificial rains in the laboratory was influenced by the particle size. A dust con-

taining DDT that would pass a 200-mesh screen but was not micronized was rendered ineffective by 3 artificial rains, while one containing micronized DDT resisted from 14 to 20 rains.

SURFACE APPLICATIONS IN OILS.—In applying DDT in petroleum oils effective control has been obtained at dosages as low as 0.1 and 0.05 pound of DDT per acre. With the small amounts of oil used the oil only serves as a carrier and spreader for the DDT, which remains after the oil film has been broken up. DDT is highly effective in oil solutions, but most of the comparisons with other types of treatment have been made in the field, and will be reported in another paper.

EMULSIONS AND SUSPENSIONS.—Both emulsions and colloidal suspensions of DDT were tested. In the case of emulsions, prepared from solutions of DDT in water-immiscible solvents, both the stable and the quick-breaking types were tried. Suspensions were made by adding solutions of DDT and wetting agents in water-miscible solvents to water. DDT was effective in all the emulsions and suspensions. At a concentration of 0.01 p.p.m. it was usually effective for 8 to 10 days.

DISCUSSION.—DDT has many advantages over other mosquito larvicides. Whereas paris green is limited in the ways it can be applied, DDT can be used as a dust or in solutions, and in emulsions. Its solubility in a wide variety of solvents, including the petroleum oils, fits it not only into oiling operations but into atomized spray, smoke, and aerosol programs, which are a radical departure from the conventional larvicidal methods.

The high toxicity of DDT permits the use of very small quantities of material. This will materially reduce the cost of transportation and application. DDT has a further advantage for use by the armed forces in the wide variety of insect pests of medical importance on which it can be used, and DDT preparations and equipment can be shifted readily from one insect problem to another. There are some disadvantages, but most of them can be overcome by changes in methods.

As a dust DDT is not toxic to warm-blooded animals except at internal doses in excess of those obtained under normal operations. In this form it is not toxic to fish and aquatic wildlife. DDT in oil at dosages recommended is not toxic to wildlife and fish, but according to toxicologists does show some slight toxicity when applied to the skin of warm-blooded animals. In suspensions DDT is toxic to fish when it is so applied as to produce concentrations above 0.1 p.p.m.

Mosquito eggs are apparently unaffected by dosages paractical for larvae. Pupae are affected to some extent, but are much more resistant than larvae. It was discovered in larvicidal applications that DDT is also effective against adults in outdoor environments, and that residues are toxic to emerging adults and ovipositing females that come to rest in the vicinity of the breeding places.

DDT will no doubt replace other toxic agents in the control of both malaria and pest mosquitoes. It will be useful not only to the armed forces but also, after the war, to the civilian population.

SUMMARY.—The high toxicity and physical properties of DDT make it very adaptable for use as a mosquito larvicide. It was tested in the laboratory using various methods of application and at different dosages, against larvae of *Anopheles quadrimaculatus* Say. The weathering of surface applications was determined by subjecting the tests to repeated artificial rains. DDT was toxic as a dust to 62 per cent of the larvae when applied at the rate of 0.0001 pound per acre. As a suspension at 0.01 p.p.m. DDT gave practically 100 per cent mortality in 48 hours, being more than 100 times as toxic as phenothiazine. DDT is adaptable to surface applications in dusts and in oils, and to use in emulsions and suspensions. It is resistant to wetting and can be used in dusts prepared from solid solutions in various diluents. In stable emulsions and suspensions at 0.1 p.p.m. it remains effective for a long time.

DDT as an Anopheline Larvicide: Preliminary Field Studies[1]

CHRISTIAN C. DEONIER, R. W. BURRELL, JOHN D. MAPLE, and J. H. COCHRAN,[2] *U.S.D.A., Agr. Res. Adm., Bureau of Entomology and Plant Quarantine*

The discovery at the Orlando, Fla., laboratory of the Bureau of Entomology and Plant Quarantine that DDT (2,2-bis (*p*-chlorophenyl)-1, 1, 1-trichloroethane), is an excellent anopheline larvicide has made possible many methods of application which are not efasible with paris green. DDT can be used (1) as a dust, (2) as a surface application in oils or other solvents, (3) in emulsions, and (4) in suspensions. Laboratory experiments (Deonier *et al.*)[3] were conducted with a wide range of DDT preparations to ascertain the more desirable larvicidal formulas for field testing. DDT was also found to be very effective against culicine mosquitoes (Eide *et al.*)[3] when applied in a form adaptable to their particular habits. Preliminary field experiments showing the efficacy of DDT agianst anopheline mosquitoes when applied in various forms are described in this paper.

The general experimental procedure was to make dipping tests before and after treatment of natural breeding places. The larval population before treatment was based on 20 to 100 dips taken in favorable places representative of the breeding environment, the number of dips depending on the size of the pool. Places that would average at least 4 or 5 larvae per dip (4.5-inch dipper) were used. The blank dips were included in the averages.

Tests were made in various types of breeding places, ranging from roadside ditches to large marshes, and in the presence of a wide variety of aquatic vegetation, including water-hyacinth, *Eichhornia crassipes* (Mart.) Solms, smartweed, *Polygonum* sp., coontail, *Ceratophyllum* sp., *Chara* sp., and several grasses. The dosage of DDT depended on whether a residual kill was desired or only an initial kill was expected.

The initial effectiveness of a treatment was found by dipping on the day following the application. The same number of dips were made as before treatment except where larvae were not found, when additional dips were taken.

The larval reduction due to the residual toxicity of DDT was determined by dipping at weekly intervals. Wherever possible a portion of the breeding area was left untreated as a check on larval development and breeding pressure. Where there was no check area and for additional confirmation where the check showed a low population, weekly samples over 1 square foot of the water surface were collected and tested biologically in the laboratory.

DDT IN DUSTS.—Dusts containing DDT applied with hand dusters consistently gave excellent control of both *Anopheles quadrimaculatus* Say and *A. crucians* Wied. under field conditions in Florida. A total of 62 field tests using DDT with various diluents were made during the summer of 1943.

Initial kill was obtained with 1 per cent of DDT in talc at dosages of 0.05 and 0.1 pound of active ingredient per acre. The results with these low dosages are given in table 1. Though the dust was immediately effective under a wide variety of conditions, such dosages were too low to give residual toxicity.

Table 1.—Initial effectiveness against anopheline larvae of low dosages of dusts containing 1 per cent of DDT in talc.

Vegetative Type	Area Treated Sq. Ft.	Larvae per Dip: Before Treatment	Larvae per Dip: After Treatment
DDT at 0.1 pound per acre			
Grass and smartweed	2,000	8.5	0
	1,105	8.2	0
Grass	1,200	2.7	0
Water-hyacinth	528	4.3	0
Smartweed and bunchgrass	9,775	3.3	0
Grassy shallow pond	65,000	5.8	0.03
	87,000	3.4	0
Dense floating grass	1,075	14.7	1.6
Floating grass	3,740	9.7	0
Weedy ditch	2,580	11.6	0
Smartweed and floating grass	1,125	13.5	0
Grass and algae	1,000	23.4	0
Smartweed ditch	2,420	13.2	0
DDT at 0.05 pound per acre			
Grassy roadside ditch	1,050	7.5	0
Grass and smartweed	2,850	20.0	0
Grass	1,300	18.7	0
	1,944	10.8	0
	1,512	10.9	0.3
	576	10.6	0.5

[1] This work was conducted under a transfer of funds, recommended by the Committee on Medical Research, from the Office of Scientific Research and Development to the Bureau of Entomology and Plant Quarantine.

[2] Acknowledgement is made of the suggestions by E. F. Knipling, and assistance of Capt. W. C. McDuffie and Edward Nottingham in conducting many of the experiments.

[3] In press.

Tests were made with a 20-per cent dust, using 1 and 2 pounds of DDT per acre, in an attempt to develop a residual toxicity so that treatment at weekly intervals, as is now done with other anopheline larvicides, would not be necessary. Because of the insolubility and non-wetting property of DDT the particles of dust remain afloat for long periods. Dust particles were recovered, and the presence of DDT was shown, for 2 to 3 months after application to natural ponds in which anophelines were breeding.

The effectiveness of DDT as a residual treatment in dust form varies with the amount and kind of vegetation in the breeding place. In the water-hyacinth type (Table 2) dipping records showed control for 6 to 8 weeks, but where the vegetation was sparse (Table 3) the wind and wave action caused drifting and broke up the dust cover, permitting breeding to recur, although in most cases control was indicated for 2 weeks after treatment.

Although most of the treatments in water-hyacinth began to fail after about 2 months, a few were effective for 3 months or more. The residual toxicity in test No. 115 (table 2) lasted for 3 months. Water samples in test No. 91 killed 95 per cent of fourth instars of *Anopheles quadrimaculatus* 11 weeks after treatment. Though some breeding was occurring, the treated area averaged less than 0.5 larva per dip while the check had 5.0 larvae per dip.

Perfect control could not be depended on even in water-hyacinth. In test No. 44 records were continued through the thirteenth week. Rains flooded this pool until it covered several acres and raised the hyacinth mat 3 feet. Though the treated area was toxic to larvae, breeding was occurring in the new growth of hyacinth that developed around the margin of the old mat. The water sample taken in the treated area gave complete mortality for fourth instars of *Anopheles quadrimaculatus* through the twelfth week, but the mortality dropped to 95 per cent on the thirteenth week. The average population in the borrow pit originally treated was never above 1.7 larvae per dip.

Table 2.—Residual toxicity of DDT applied as a dust to natural anopheline breeding areas having a heavy growth of water-hyacinth.

Test No.	Total Rainfall (Inches)	Larvae per Dip Before Treatment	Larvae per Dip (Weeks after Treatment)							
			1	2	3	4	5	6	7	8
DDT at 1 pound per acre										
35	11.6	9.3	0.03	0.85	0.6	0.08	0.15	0.25	0.25	—
36	11.6	6.9	0	.76	.2	.3	.8	.46	.27	—
Check	11.6	6.7	12.9	9.8	6.3	4.5	2.9	4.1	2.0	—
DDT at 2 pounds per acre										
43	17.0	9.1	0	0	0	0	0	0	0	0
Check	17.0	6.2	4.9	2.4	.7	.1	4.3	3.5	1.6	3.5
44	22.2	5.7	.04	.4	.17	.23	.15	1.0	1.5	1.3
91	10.5	5.5	0	0	0	.1	.2	.5	.3	.4
(No check made)										
96	10.5	9.3	0	.06	.03	.03	.5	.3	.5	.3
97	10.5	7.8	0	.03	.03	.06	.2	.3	.1	.03
Check	10.5	9.7	6.7	13.5	7.3	12.6	7.0	5.2	9.9	6.3
114	6.5	12.2	0	0	.7	2.2	11.4	—	—	—
115	8.0	11.8	0	0.15	.1	.6	.05	1.0	.05	.35
Check	8.0	9.9	12.0	13.1	11.6	6.5	11.0	20.1	16.1	13.2

SURFACE APPLICATIONS IN PETROLEUM OILS.—DDT dissolved in petroleum oils makes an effective larvicide, and its inclusion greatly reduces the amount of oil required. The oil serves only as a carrier, which spreads the DDT on the surface of the water and leaves it as a toxic residue after the oil has dissipated. Field applications have been made on various types of pools and on running streams. Various

methods of application have been used, such as spraying, pouring, and releasing from drip cans or from under-water oil dispensers and porous materials that have been soaked in oil.

In a series of tests the DDT was applied at different dosages dissolved in No. 2 fuel oil and in waste crankcase oil. The percentage of DDT in the oil was also varied when the dosage was constant. Dosages of less than 0.1 pound per acre of 5 per cent DDT utilized such small quantities of oil as to make adequate coverage difficult even when the oil was broken up into a very fine spray.

One quart per acre of No. 2 fuel oil containing 5 per cent of DDT (0.1 pound of DDT per acre) gave control of anophelines in average vegetation. The effectiveness of such a small amount of oil was due to the DDT. At such a dosage the control depends on how well the oil spreads and penetrates. Since coverage was sometimes difficult to obtain with the small amount of oil in the dosage when a 5 per cent solution was used, tests were made with 0.1, 0.6, and 1.0 per cent solutions of DDT. With 0.1 per cent of DDT a dosage of 0.1 pound per acre would require 12 gallons of oil. With 10 gallons or more of oil, however, the oil alone would be so effective that the effect of low percentages of DDT would not be discernible.

In most instances the oil was applied by spraying; yet even with careful application 100 per cent control was not obtained so frequently as with dusts. Oil solutions have been used with success in streams and can be used in dispensers which release the oil slowly over a long period of time.

Oil solutions will be used by the armed forces much more widely than dusts because of the ease of application, availability of carrier, and adaptability to existing equipment.

As a residual larvicide the use of DDT in oils as a surface application is subject to the same limitations as dusts. It is possible, however, that in oils the DDT might adhere more closely to the vegetation with which the larvae would come in contact.

The tests with DDT in fuel oil are summarized in table 4. These results indicate that there was no significant difference between 0.6, 1.0, and 5.0 per cent of DDT in oil when applied at the rate of 0.1 pound per acre.

Table 3.—Residual toxicity of DDT applied as a dust in natural anopheline breeding places other than water-hyacinth.

Vegetative Type	Area Treated Sq. Ft.	Larvae per Dip			
		Before Treatment	After 24 Hours	After 1 Week	After 2 Weeks
DDT at 0.1 pound per acre					
Grass and smartweed	2,000	8.5	0	2.2[1]	—
Weeds and bunchgrass	9,775	3.3	0	9.0	—
Grassy shallow pond	165,340	5.8	.03	2.2	—
	87,120	3.4	0	4.3	—
Floating grass	3,740	9.7	0	.8	—
Weedy ditch	2,580	11.6	0	2.9	—
DDT at 1.0 pound per acre					
Grassy shallow pond	2,500	1.6	0	1.0	Dry
	4,800	2.3	0	.4	0.3
	7,250	2.3	.03	.52	—
Shallow grassy	2,850	9.1	0	1.8[2]	—
Grassy limesink	1,600	8.2	0	.45	—
Weedy hyacinth, loose	69,696	21.8	0	1.2	5.4
DDT at 2.0 pounds per acre					
Roadside ditch	4,835	3.9	0	.1	.7
	5,662	12.1	0	1.0	.3
Barrow pit	15,246	5.4	0	.9	2.0
Shallow pond	13,285	13.1	0	3.5	8.7
Weeds and bunchgrass	8,750	9.0	0	.9	.4

[1] No larvae larger than an early third instar.
[2] No larvae larger than a second instar.

Table 4.—Toxicity of DDT when applied in No. 2 fuel oil to natural anopheline breeding places.

Dosage per Acre				Larvae per Dip		
DDT, Pounds	Oil, Gallons	Vegetative Type	Area Treated, Sq. Ft.	Before Treatment	After Treatment	Per Cent Reduction
		0.1 per cent of DDT				
0.05	6.0	Dense floating grass	962	26.8	5.8	78.4
			240	31.4	7.6	75.8
		Open pond	1,082	9.9	.15	98.5
		0.6 per cent of DDT				
.05	1.0	Dense *Chara*	153	12.6	1.7	87.3
		Chara	3,910	20.5	.6	97.1
.1	2.0	Smartweed and floating grass	4,776	15.8	1.1	92.9
			720	9.1	.1	98.9
			1,470	14.4	.2	98.9
			952	7.6	.1	98.7
.25	5.0	Grassy ditch	7,350	12.8	1.1	91.5
.5	10.0	Dense floating grass	6,510	10.0	1.4	86.4
		Smartweed, grass, and coontail	2,540	14.3	0	100.0
1.0	20.0	Smartweed	700	13.7	0	100.0
		Water-hyacinth	2,640	4.2	.1	97.6
		1.0 per cent of DDT				
0.05	0.6	Grassy	2,400	4.5	.2	95.5
		Smartweed and floating grass	800	10.1	8.4	16.8
.1	1.2	Grassy ditch	720	5.2	.5	89.0
		Smartweed ditch	350	18.8	.4	97.0
		Floating grass	1,276	16.3	.4	97.4
			1,276	21.2	.6	97.2
		Smartweed and floating grass	465	16.2	.4	97.5
.2	2.4	Smartweed and floating grass	1,188	14.2	.3	97.8
		5.0 per cent of DDT				
.05	.12	Smartweed and floating grass	360	16.2	3.3	80.1
		Open ditch with grass	2,400	3.7	.4	89.3
.1	.24	Floating grass	2,438	9.0	.25	97.2
			3,055	15.1	.05	99.7
		Smartweed	276	5.8	0	100.0
		Open ditch with grass	560	4.0	.4	90.4
.5	1.2	Smartweed	875	14.5	0	100.0
		Smartweed and floating grass	1,207	9.8	0	100.0
			1,152	14.1	0	100.0
1.0	2.4	Smartweed and floating grass	1,092	12.8	0	100.0
			1,300	8.6	.05	99.5

In tests with DDT in waste crankcase oil (Table 5) excellent results were obtained until toward the end of the rainy season, when it was found that this oil would not spread on some of the breeding places. The crankcase oil treatments were applied by pouring, the natural spread of the oil being depended on to give coverage.

DDT IN SUSPENSIONS AND EMULSIONS.—DDT in suspensions was found to make a very efficient larvicide. One formula—DDT 10 per cent, *Cellosolve* (ethyl ether of ethylene glycol) 80 per cent, and *Nopco 1216* (sulfonated sperm oil) 10 per cent—gives a very stable suspension in which the solvent is miscible with water, leaving the DDT in colloidal suspension. Another—DDT 20 per cent, *Triton X-100* (an aralkyl polyether alcohol) 20 per cent, and xylene

60 per cent—forms an emulsion when the concentrate is mixed with water, and the DDT remains in solution in the water-immiscible xylene, which is dispersed in colloidal-sized droplets. When the xylene emulsion was applied at a concentration of 0.05 part per million of active ingredient, control was obtained in both fresh and brackish waters.

Field tests with the DDT-xylene concentrate are summarized in table 6. The emulsion was applied from an ordinary spray cylinder. In some of the tests the wading of the operator did not stir up the water, and it has since been found that unless there is wind and wave action diffusion and mixing will not occur in 24 hours. Therefore, the dosage at the surface of the pools may have been greater than calculated.

Higher concentrations of DDT in stable suspensions offer considerable promise as a long-lasting larvicide. Stable suspensions have lasted as long as 3 months in the field. At high concentrations, however, DDT is toxic to cold-blooded animal life, killing fish, frogs, and snakes in addition to the aquatic insects.

DISCUSSION.—Paris green, though highly toxic to anopheline larvae, is limited in the ways in which it can be applied. A light shower renders it ineffective against larvae feeding at the surface of the water. DDT was found to be inherently resistant to wetting and to withstand heavy rains. Other factors, such as wind and wave action, were found to be more important in preventing residual toxicity than sinking by rain. DDT can be diluted to as little as 1 per cent in an inert material without seriously impairing its efficiency. With paris green, on the other hand, high dilution has been found to reduce the kill (Shipizina 1938, Hinman *et al.* 1942).

Table 5.—Toxicity of DDT when applied in waste crankcase oil to natural anopheline breeding places.

Dosage per Acre				Larvae per Dip		
DDT, Pounds	Oil, Gallons	Vegetative Type	Area Treated Sq. Ft.	Before Treatment	After Treatment	Per Cent Reduction
		0.6 per cent of DDT				
0.1	2.0	Smartweed and floating grass	1,540	15.6	0.1	99.4
			525	8.1	0	100.0
		Smartweed ditch	616	8.5	.3	96.5
		5.0 per cent of DDT				
	.24	*Pontederia* pot hole	1,735	7.7	.3	96.1
			1,320	7.5	.4	94.7
		Dense *Chara* and algae scum	4,360	11.5	.5	95.6
		Dense grass	2,706	8.4	.25	97.0
.5	1.2	Weedy ditch	950	10.9	0	100.0
		Roadside ditch	9,505			0[1]

[1] Crankcase oil would not spread.

DDT, a synthetic organic compound, is adaptable to many methods of application. Data have been given on the basic forms in which it can be applied. Modification of these forms can be made to suit local conditions and the availability of diluents or equipment. M. A. Barber, who has collaborated with this Bureau, obtained excellent results with crankcase oil.

Table 6.—Toxicity of DDT when applied in xylene emulsion to anopheline breeding places.

Vegetative Type	Volume Treated	Larvae per Dip		Per Cent Reduction
		Before Treatment	After Treatment	
DDT at 0.0125 p.p.m.				
Chara	1,735	14.6	0.25	98.3
Dense vegetation	18,061	12.3	0.3	97.5
Grassy pot hole	45	20.0	0	100.0
	169	9.6	0	100.0
Ditch, emergent grass	3,400	11.2	.02	99.9
DDT at 0.05 p.p.m.				
Chara, roadside ditch	2,033	11.6	0	100.0
Pond, emergent grass	43,560	3.0	.008	99.7
DDT at 0.1 p.p.m.				
Dense smartweed	2,705	12.5	.05	99.6

Oil solutions of DDT can, of course, be used in many of the special methods of applying larvicidal oils that have been used in the past.

Many new methods of application, such as airplane sprays, aerosols, and spray mists, have been made possible by the small amounts of materials required per unit of area. These an other methods, including special oil dispensers, smokes, an grenades, as well as prebreeding treatments, are being investigated. Not only are adaptations of DDT to existing equipment being studied, but also the development of new equipment especially designed for dispensing concentrated insecticides and methods of application where no equipment is available.

DDT has many desirable features which makes it more useful from a military standpoint than any of the larvicides previously used. The wide range of insects affecting the armed forces which DDT will control would eliminate the necessity of supplying several toxic agents. DDT mixtures in concentrated form would save critical shipping space not only in transportation to supply points in the various war theatres but also in moving the larvicide from supply depots to the actual point of use.

These advantages, together with a reduction in the cost of application, will also be important when DDT is available for domestic consumption after the war.

SUMMARY.—In preliminary field tests DDT was found to give effective control of *Anopheles quadrimaculatus* Say larvae at dosages as low as 0.05 and 0.1 pound per acre. Such low rates of application provide little lasting effects, and breeding will be resumed within a few days after treatment.

Applications of DDT in dust form at rates of 1 to 2 pounds per acre provide effective lasting effect if applied in vegetative growth. In breeding areas having light to moderate vegetation the heavy treatments usually show a reduction of breeding for 1 to 2 weeks, but wind action and other surface disturbances break up the protective dust cover, and permit breeding to recur.

Five per cent of DDT in petroleum oil is effective in average vegetation at a dosage of only 1 quart of oil per acre; a larger quantity may be needed to secure adequate coverage in many situations. Application may be made by pouring, by spraying, and from dispensers or porous materials. It can also be applied by various special methods that have been developed for other larvicidal oils. When using oils a long-lasting treatment may be obtained by the slow release of the larvicide. Wind and wave action in breeding areas having light to moderate vegetation break up the surface film of oils and DDT deposits the same as with dusts.

In xylene emulsion DDT was toxic at 0.05 part per million. A long-lasting larvicide was obtained with higher concentrations of DDT in colloidal suspensions, but such suspensions were toxic to cold-blooded animal life.

DDT mixtures in concentrated form would greatly simplify problems of transportation and treatment.

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STATE QUARANTINES REVOKED

The State of Idaho, in December 1944, revoked its quarantines against the cherry fruitfly, the Colorado potato beetle, the oriental fruit moth, the strawberry weevil, the pea weevil, the vetch weevil, and the pear psylla.

Oregon quarantines on account of the virus disease of *rubus* in other States and gladiolus thrip in that State were revoked in 1944.

The State of Oklahoma repealed its vetch weevil quarantine in August 1944.

DR. PARKER ON LEAVE IN BERMUDA

Dr. R. L. Parker has been granted a three months' leave of absence from Kansas State College to carry out a special assignment of investigating injurious insects attacking the Bermuda cedar. He will be Consulting Entomologist with the Bermuda Board of Agriculture, Paget East, Bermuda. The insect causing the principal damage is the juniper midge, *Contarinia juniperina*, or a closely related species.

DDT for the Control of *Psorophora* Mosquitoes

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Mosquitoes of the genus *Psorophora* are annoying pests in the Southeastern States. The two most prominent species found in peninsular Florida are the Florida glades mosquito, *P. columbiae* (D. & K.), and the shaggy-legged gallinipper, *P. ciliata* (F.). Because of the severe biting habits of these insects, their presence in large numbers has frequently been disastrous to the morale of military personnel stationed in localities where these mosquitoes are found.

Since *Psorophora* larvae develop in a very short time, it is imperative that treatment be made within a few days after hatching. This is frequently difficult when large areas are flooded. Owing to the females' habit of ovipositing on sod which may later become flooded, it seemed possible that prehatching treatments might be applied to favorable environments. Investigations along this line at Orlando, Fla., have brought very gratifying results. Since *Aedes* mosquitoes have similar egg-laying habits, it is possible that prehatching treatments may also be practicable against larvae of this group.

It was known that oviposition occurs late in the fall in roadside ditches and grassy swales throughout this area, and that an abundant new crop of adults appears within a week after the first heavy rains in the spring. Sod samples from several such locations, when subjected to flooding in the laboratory, showed the presence of viable eggs and indicated areas for prehatching treatments. These treatments, which were made during March and April 1944, consisted in applying dusts and sprays containing varying amounts of DDT to the sod and in placing self-operating oil dispensers so that subsequent flooding would release the oil-dissolved DDT. Flooded areas which had not been subjected to prehatching treatments, and which showed satisfactory larval populations, were used for studying the effects of surface applications of DDT.

Table 1.—Prehatching treatments for the control of *Psorophora* spp.

Material	Amount of Material Applied	Area Treated	Dosage of DDT	Time Between Application and First Flooding	Control at First Flooding	Control at Second Flooding
		Square Feet	*Pounds per Acre*	*Days*		
Dusts:						
20% DDT in talc	80 gm.	1,540	1.0	28	None	—
1% DDT in talc	160 gm.	1,540	.1	17	None	—
Oil dispenser:						
5% DDT in No. 2 fuel oil	950 ml.	2,425	1.8	6	Perfect	Poor
	950 ml.	43,560	.1	6	Perfect	None
Sprays:						
1% DDT in No. 2 fuel oil	135 ml.	1,300	.1	6	Perfect	None
5% DDT in No. 2 fuel oil	40 ml.	900	.1	6	Perfect	—
	950 ml.	85,000	.1	14	Perfect	—
20% DDT xylene emulsion	104 ml. in ½ gal. water	10,000	.2	14	Perfect	—

The rain that fell on March 7 was sufficient to induce some hatching of *Psorophora* larvae, but the pools were too temporary for complete development of a brood. A heavy downpour on March 12 filled many of the pools and alllowed satisfactory development. An even heavier rain on March 30 flooded enough more of the treated areas to give data from all types of treatments that had been applied,

[1] This work was conducted under a transfer of funds, recommended by the Committee on Medical Research, from the Office of Scientific Research and Development to the Bureau of Entomology and Plant Quarantine.

[2] Edward Nottingham assisted in conducting these tests.

and induced larval development in sufficient other pools to permit a large series of surface applications to be made. The data relative to the prehatching treatments are presented in table 1, and those from the various forms of surface applications of DDT in table 2.

In the prehatching treatments the 1 per cent dust which had been applied at the rate of 0.1 pound of DDT per acre gave no control after 17 days of weathering, while the 20 per cent dust applied at the rate of 1.0 pound of DDT per acre was not effective after 28 days of exposure. It is possible that, if the rain which fell 6 days after the applications had been sufficient to flood these ponds, satisfactory control would have been obtained. The oil spray containing 1 per cent of DDT applied at the rate of 0.1 pound of DDT per acre gave perfect control after 4 days' exposure, but gave no control at the second flooding 18 days later.

Both an oil spray at 0.1 pound and a xylene emulsion at 0.2 pound of DDT per acre gave perfect control when the areas were flooded after 14 days of exposure, which included a heavy shower that was insufficient to cause flooding. It was noted that recently hatched larvae could be found at these locations, but that no subsequent development took place whereas development was very rapid in adjacent untreated areas.

Only two of the several oil dispensers that had been installed were flooded, but the results from the use of this apparatus were similar to those obtained from the prehatching application of oil sprays. Perfect control was obtained in plots where flood waters had covered an acre and 0.5 acre, both areas receiving 1 quart of oil containing 5 per cent of DDT. The subsequent poor control at the second flooding indicated that it probably will be necessary to refill the oil dispensers or to spray the areas during the periods between rains.

The data from the various surface applications, presented in table 2, indicate control of these pests through the application of DDT at the rate of 0.1 pound per acre by dusting, pouring of oil, spraying of oil or xylene emulsions, or the use of impregnated sawdust. The drifting of

Table 2.—Treatments for control of *Psorophora* spp. applied after the eggs had hatched.

Material	Amount of Material Applied	Area Treated	Dosage of DDT	Average Number of Larvae per Dip		
				Before	After	
		Square Feet	*Pounds per Acre*			
			Dusts:			
20% DDT in talc	625 gm.	1,200	1.0	5.8	0.5	*P. ciliata* alive, but specimens died in 48 hours
1% DDT in talc	125 gm.	1,200	.1	5.0	0	3.6 average in check
	235 gm.	2,250	.1	3.0	.05	
			Poured oil:			
Fuel oil alone	1.04 ml.	10		7.1	3.5	Fuel oil alone not effective
5% DDT in jeep oil[1]	13 ml.	860	.08	4.2	0	Larvae present 30 feet away in grass[2]
	16 ml.	620	.12	3.0	0	
			Impregnated sawdust:			
5% DDT in fuel oil	13 gm.	200	.15	2.3	.05	Extra DDT to compensate for amount adhering to sawdust
	13.5 gm.	216	.15	2.2	0	
	34 gm.	1,620	.15	2.2	0	
			Sprays:			
20% DDT xylene emulsion	2.2 ml. in 1 gal. water	1,800	.025	2.0	0	Applied as a suspension
	85 ml. in ½ gal. water	16,000	.1	4.2	0	Drifted spray gave perfect control for 100 feet, no control beyond that distance
	11 ml. in ½ gal. water	1,950	.1	3.0	0	Drifted spray gave perfect control over 30-foot width of pool
	8 ml. in ½ gal. water	1,500	.1	5.3	0	
1% DDT in No. 2 fuel oil	750 ml.	720	1.0	7.0	0	
	125 ml.	1,200	.1	7.5	0	
5% DDT in No. 2 fuel oil	200 ml.	18,720	.05	2.0	1	Drifted spray not effective against last instars

[1] Used crankcase oil.
[2] Poured oils frequently have very restricted spread among vegetation in central Florida.

mechanically dispersed mists gave good control of young larvae, but was not very effective against the last instars. It is probable that effective control of *Psorophora* can be obtained with DDT at dosages considerably lower than 0.1 pound per acre.

In contrast to the results obtained from the prehatching treatments, it appeared that there was definite residual toxicity in the plots which had received surface treatments at the first flooding. It probably would be inadvisable, however, to depend on this factor in actual control practice.

SUMMARY.—Small-scale field tests on the use of DDT for the control of *Psorophora* mosquitoes were conducted in roadside ditches and pasture pools near Orlando, during March and April 1944.

Prehatching sprays of fuel oil or xylene emulsion containing DDT gave perfect control at 0.1 and 0.2 pound of DDT per acre after 2 weeks or more exposure prior to flooding of the treated area. A self-releasing oil dispenser applying DDT at 1.8 and 0.1 pound per acre also gave perfect control before the second flooding. Dusts containing DDT were not satisfactory under the conditions of these tests.

Surface applications made after the eggs had hatched showed that treatments of less than 0.1 pound of DDT per acre gave satisfactory control of all but the largest larvae, whether applied as dusts or sprays, in oil impregnated sawdust, or poured oil.

DDT Treatment of Airplanes to Prevent Introduction of Noxious Insects

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The present method of guarding against the introduction of disease-carrying and destructive pest insects into the United States through air transport is to disinfest airplanes with the *Freon*-pyrethrum aerosol (Sullivan *et al.* 1942). Although this treatment is very effective against flying insects, the persistent toxicity of DDT when used as a residual-type treatment, as discussed by Madden *et al.* (p. 265) and Gahan *et al.* (p. 231), suggested the possibility that one application of this material would remain effective for several weeks and serve as an extra safeguard. Inasmuch as the treatment of airplanes presents a special problem apart from those involved in treating buildings, tents, and similar structures investigations were undertaken by the Bureau of Entomology and Plant Quarantine at Orlando, Fla., to obtain information on the effectiveness and feasibility of such treatments.

LABORATORY TESTS.—In preliminary tests the treatments were applied to the inside surface of glass battery jars, 9 inches high by 6 inches in diameter, at the rate of 100 mg. of DDT per square foot. Houseflies were introduced at intervals after treatment, and the time to first and to complete knock-down was recorded. Eight spray treatments, including 5, 20, 30, and 50 per cent of DDT in various solvents, and one dust containing 50 per cent of DDT in talc, were evaluated. All except a spray treatment containing 20 per cent of DDT were quite resistant to wiping with a dry cloth. The spray treatment was no more effective than the dust after two wipings of the jars, but gave definitely superior results after a third wiping. None of the treatments was completely resistant to washing with soap and water.

Further laboratory tests were conducted in which two large semicylindrical cages of approximately 48 cubic feet in capacity, constructed of glass and aluminum to simulate a section of an airplane fuselage, were used. These cages were treated with 20 per cent of DDT, one as a spray in kerosene and the other as a dust in talc, at the rate of 100 mg. of DDT per square foot. Sixty-two per cent of the

[1] The writers wish to acknowledge the cooperation and assistance of Comdr. Omar J. Brown, Bureau of Medicine and Surgery; Lt. G. S. Hensill, sanitation officer, and Lts. (j.g.) Roy Young, Richard Daggy, and Barney Slocum, Naval Air Station, Jacksonville, Fla.; and Lt. Col. J. Q. A. Daniels, Capt. N. U. Rokes, and Lt. John A. Kizer, Army Air Forces Tactical Center, Orlando, Fla. F. A. Morton treated most of the airplanes and made the initial check at Jacksonville, and some of the laboratory experiments were performed by Douglass Burnett, Jr.

[2] This work was conducted under a transfer of funds, recommended by the Committee on Medical Research, from the Office of Scientific Research and Development to the Bureau of Entomology and Plant Quarantine.

dust settled to the floor of the cage during treatment and was removed with the paper floor covering when the cages were wiped. Since in practice the floor of a plane is kept clean, it appears inevitable that a large portion of a dust treatment will be removed shortly after application.

Houseflies and mosquitoes were released in the cages, and the time to the first and to complete knock-down was determined. The action of the dust treatment was slower than that of the spray, particularly with respect to the knock-down of mosquitoes. Wiping the cages with a dry cloth 11 days after treatment reduced the knock-down rate of both insects. The cages were washed with kerosene 19 days after treatment to simulate a method of cleaning sometimes used in military planes. This washing decreased the action of the dust treatment to a marked extent, but had no noticeable effect on the spray treatment.

AIRPLANE TESTS.—Final tests were made in airplanes under actual operational conditions. The majority of these tests were conducted at the Naval Air Station, Jacksonville, Fla., and others at the Army Air Force Tactical Center, Orlando, Fla. Treatments consisted of 5 and 20 per cent of DDT in various formulas in kerosene solutions, 20 per cent of DDT in an aqueous emulsion, applied as wet and fine-mist sprays, and 50 per cent of DDT in talc applied as a dust. Two treatments with an aerosol containing 5 per cent of DDT and 0.2 per cent of pyrethrins were included.

The aerosol treatments were made to determine the possibility of obtaining an effective residue with the DDT-pyrethrum aerosol formula. Four or five times the recommended dosage was used, and the nozzle of the sprayer was directed so as to deposit DDT on all surfaces. Dusts were applied by blowing the material into all parts of the plane from a central point with a plunger-type duster, the average dosage being 2 ounces. Wet sprays were applied as in painting, with the nozzle adjusted to produce coarse droplets. With this treatment about 300 ml. of solution was needed to treat an average-size fighter plane, while 1,300 to 1,500 ml. was needed for a PBY flying boat. Fine-mist sprays were applied in somewhat the same manner as the dusts, with the nozzle adjusted to give fine droplets. The emulsion left an unsightly deposit, which undoubtedly would be removed by plane crews in the absence of instructions to the contrary.

Applications were made with the doors, windows, and hatches of the airplanes closed, and in the confined space all the sprays were very irritating. In case of prolonged or repeated exposures to the vapors produced by such sprays, or aerosols, it appears desirable to wear a gas mask of the all-service type. From the standpoint of ease of application, the dust and aerosol would rank first, the fine-mist spray second, and the wet spray third.

Several types of sprayers were tested in connection with the spray applications. The one found to be most satisfactory was a small cylinder-type, compressed-air hand outfit. For discharging the fine-mist spray it was fitted with a nozzle disc with a No. 73 hole (standard wire gauge). (A No. 73 disc hole cannot be used in connection with all types of hand-operated pressure sprayers. With some it produces a straight fine stream of liquid instead of a fine-mist spray.) The nozzle and the release valve were attached to the cylinder with about 5 feet of rubber hose, to provide the maximum freedom of movement, and since the air chamber could be charged with enough air to complete one application, the operator merely moved backward through the plane directing the nozzle in an arc toward the upper surfaces. This spray drifted well, and yet the droplets were large enough to adhere to the surfaces contacted.

Evaluation of the treatments was made at intervals up to 9 weeks after application by exposing estimated numbers of laboratory-reared houseflies and mosquitoes in treated airplanes for 1½ to 2 hours and then counting the insects that were down. Previous experience with insects exposed to DDT has shown that knock-down is synonymous with kill except under special conditions of temperature (Lindquist *et al.* 1945). Three species of mosquitoes—*Anopheles quadrimaculatus* Say, *Aëdes aegypti* (L.), and *Culex quinquefasciatus* Say—were used in these tests. The short exposures gave the treatments a severe test, but the planes were seldom on the ground for a longer period. Houseflies were left in an untreated plane for 2 days without food or water, with only 10 per cent mortality. Thus it is evi-

dent that none of the knock-down recorded in the treated planes can be attributed to natural causes.

The aerosol treatment applied to an airplane with upholstered interior gave 42 per cent knock-down of houseflies 3 weeks after application, whereas the same treatment applied to another airplane with uncovered metal interior gave no knock-down even after 2 weeks. This indicates that particles of DDT applied in aerosol form adhere for a longer time to fabrics than to metal surfaces. The results of these tests suggest that a fairly effective residue may be built up in a plane with repeated use of a DDT-pyrethrum aerosol for regular disinfestation purposes.

Dust treatments gave a maximum knock-down of 42 per cent of the mosquitoes in airplanes with metal interiors at the end of 2 weeks, but a dust applied in an upholstered plane gave 100 per cent knock-down after 6 weeks. These results show that a dust does not adhere well to metal and is readily removed by cleaning, vibration, or air-wash through the plane while it is in flight.

Wet sprays containing 5 per cent of DDT gave 80 per cent knock-down of mosquitoes 6 weeks after application. Slightly better results were obtained when a mixture containing 20 per cent of DDT in kerosene was applied as a fine-mist spray, and only about one-fifth as much solution was required.

Several airplanes with upholstered interiors were treated with a kerosene solution containing 20 per cent of DDT applied as a fine-mist spray at the rate of 28 to 35 ml. per plane, but when examined 3 weeks later practically no knock-down of houseflies and mosquitoes was obtained in 2 hours. The treatment was repeated in another plane of the same type, but 400 ml. of solution was used. Twelve days later complete knock-down of houseflies and mosquitoes was obtained within 2 hours, the first knock-down of flies occurring in 15 minutes. The dosage used in the final test (approximately 350 mg. per square foot) was probably higher than necessary, since houseflies have been killed in the laboratory by exposure to the same type of upholstering cloth treated with 100 mg. of DDT per square foot.

CONCLUSIONS.—Although these tests are not considered sufficiently conclusive to justify recommendations, the results indicate that DDT residue treatment of airplanes represents a rather satisfactory supplement to the present aerosol treatment. It will afford protection in cases where the aerosol is improperly applied, or omitted, and also provides a means of treating the inside of the wings, tail assembly, engine mounts, and landing gear recesses, which cannot be treated effectively with an aerosol. It is recognized, however, that the residue treatment may not be a complete substitute for the aerosol treatment, because during short flights, or in the presence of untreated baggage or cargo, mosquitoes and other insects might not rest on treated surfaces long enough to obtain a toxic dose. No harmful effects were produced by the DDT deposit and the solvents on either the interior of the plane or the occupants.

Practical tests are needed in cargo and transport planes making regular flights, to determine the effectiveness of DDT residue treatments against all types of noxious insects under all kinds of flying conditions.

SUMMARY.—Laboratory and field investigations show that DDT residue treatments in airplanes provide effective toxic action against mosquitoes and houseflies for at least 6 weeks under expreimental conditions. Airplanes which were in operational use were treated with various DDT solutions, an emulsion, and a dust. At intervals mosquitoes and flies were placed in the planes to observe the length of time required for knock-down and kill. Dust treatments are not so satisfactory as sprays from the standpoint of duration of effectiveness, except where applied to upholstered surfaces, and this fact, together with the unsightliness of the deposit, counterbalances the greater ease of application of dusts. The best spray treatments gave a high knock-down of mosquitoes and houseflies after an exposure period of 2 hours. The most satisfactory treatment appears to be a 20 per cent concentration of DDT applied as a fine-mist spray.—3-13-45.

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DDT and Pyrethrum Aerosols to Control Mosquitoes and Houseflies under Semi-Practical Conditions[1]

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The application of insecticides in the form of aerosols produced by spraying solutions in a liquefied gas (Sullivan, *et al.* 1942) has proved to be an effective method of insect control. A solution of pyrethrum and sesame oil in dichlorodifluoromethane (*Freon-12*) has been used successfully, particularly against certain disease-carrying species, such as mosquitoes and houseflies. Because of the shortage of pyrethrum, however, a project was initiated at the Orlando, Fla., laboratory of the Bureau of Entomology and Plant Quarantine in May 1943 for the purpose of investigating the possibility of finding a substitute for it or reducing the amount used in the regular formula. Preliminary tests in February 1943, had indicated that DDT (2,2-bis(*p*-chlorophenyl)-1,1,1-trichloroethane) in an aerosol was the most effective of several new insecticides tested against houseflies. For this reason extensive comparative tests were made with DDT and pyrethrum aerosols against the common malaria mosquito, *Anopheles quadrimaculatus* Say, and the housefly, *Musca domestica* L. This paper represents a general discussion of the results for the purpose of acquainting other workers with the progress made. Unfortunately the formulas used cannot be included.

METHODS.—Tests were conducted in closed rooms of 4,800 to 9,300 cubic foot capacity against laboratory-reared 2-day-old mosquitoes and 4-day-old houseflies.

The aerosols were dispersed from a regular 1-pound container equipped with a rapid shut-off device. The approximate amount of aerosol desired for a test was obtained by discharging for the number of seconds indicated by previous calibration of the nozzle. The exact amount used was determined by weighing the container before and after discharge on a balance sensitive to 20 mg.

A special dispenser, described by McGovran *et al.* (1943), was used in some tests. The desired amount of aerosol was placed in this dispenser, and it was then necessary merely to open the valve and deliver the entire contents.

The aerosol was distributed evenly about the test room by operating a 16-inch electric fan for 1 minute after discharge. The mosquitoes were then exposed for 1 minute and the houseflies for 5 minutes by carrying them around the room in cylindrical 16-mesh wire cages 7.5 inches long and 2.75 inches in diameter. Immediately after exposure the insects were transferred to clean holding cages of the same size, and knock-down records were taken at intervals up to 2 hours. They were then fed and watered and held at a fairly constant temperature and humidity until the following day, when mortality counts were made.

The room was aired and the exposure cages washed thoroughly in acetone after each test to prevent residual insecticidal action. Unexposed insects were used as checks, and if the 24-hour mortality reached 20 per cent for any test, the records were discarded. As a rule, however, there was little or no mortality in the check cages.

RESULTS.—Initial tests demonstrated that DDT is not sufficiently soluble in *Freon-12* to provide a satisfactory concentration without the use of an auxiliary solvent. In extensive tests of a number of such solvents cyclohexanone was found to be the most desirable. A DDT formula containing this solvent was tested in comparison with the pyrethrum aerosol being used by the armed forces. Comparisons were made at dosages approaching the median lethal dosage, and also at 1.5 and 3 grams of total aerosol per 1000 cubic feet. The last dosage is that recommended for practical application. The results are summarized in table 1. At a concentration of DDT 12.5 times that of the pyrethrins, the two insecticides were about equally toxic to mosquitoes, particularly at the higher dosages. To houseflies, on the other hand, DDT was far more toxic than was pyrethrum. The 10-minute knock-down of both types of insects with

[1] This work was conducted under a transfer of funds, recommended by the Committee on Medical Research, from the Office of Scientific Research and Development to the Bureau of Entomology and Plant Quarantine.

Table 1.—Comparison of the effectiveness against mosquitoes and houseflies of pyrethrum and DDT aerosols at three dosages. From 75 to 100 insects were used in each test.

Insecticide and Dosage	Tests	*Anopheles quadrimaculatus*			*Musca domestica*		
		Knock-down in—		Kill in 24 Hours	Knock-down in—		Kill in 24 Hours
		10 Minutes	2 Hours		10 Minutes	2 Hours	
	Number						
Median lethal:							
Pyrethrum	14	60	83	79	—	—	—
DDT	19	2	28	62	0	30	98
One-half recommended:							
Pyrethrum	7	99	99.6	100	57	24	13
DDT	8	7	92	98	5	98	100
Recommended:							
Pyrethrum	9	99	100	100	88	61	11
DDT	9	19	100	97	39	100	100

DDT was, however, relatively low.

In order to combine the desirable knock-down property of pyrethrum with the higher toxicity of DDT to houseflies, tests were conducted with aerosols containing both insecticides. The results are shown in table 2. With this combination none of the toxicity to houseflies was lost and the toxicity to mosquitoes was increased slightly over that obtained with the standard pyrethrum aerosol. At the higher dosages knock-down of both insects was approximately equal to that caused by the pyrethrum aerosol.

To determine the possibilities of improving the DDT aerosol by including materials other than pyrethrum, various fatty materials and wetting agents were added to the formula. None of these appreciably increased the effectiveness of DDT with respect to either knock-down or kill.

A rather extensive series of tests showed that other oils could be substituted for sesame oil in the pyrethrum aerosol. It was learned also that motor oils of various viscosities increased the toxicity of DDT to an appreciable extent. With this information available, a formula containing less DDT than was used in earlier tests was developed. It was also possible to reduce the percentage of auxiliary solvent needed to keep the DDT in solution.

Table 2.—Comparative effectiveness of the pyrethrum and DDT-pyrethrum aerosols against mosquitoes and houseflies at three dosage rates. From 75 to 100 insects used in each test.

Insecticide and Dosage	Tests Number	Knock-down in—		Kill in 24 Hours
		10 Min.	2 Hours	
		per cent		
Anopheles quadrimaculatus				
Median lethal:				
Pyrethrum	14	60	83	79
DDT+pyrethrum	6	9	48	85
One-half recommended:				
Pyrethrum	10	99	100	100
DDT+pyrethrum	9	77	99	100
Recommended:				
Pyrethrum	9	99	100	100
DDT+pyrethrum	10	91	99	100
Musca domestica				
Median lethal:				
Pyrethrum	—	—	—	—
DDT+pyrethrum	4	0	30	90
One-half recommended:				
Pyrethrum	10	78	12	5
DDT+pyrethrum	9	75	96	100
Recommended:				
Pyrethrum	11	98	66	11
DDT+pyrethrum	12	91	99	100

Table 3.—Comparative effectiveness of the standard pyrethrum and DDT-pyrethrum-motor oil aerosols against mosquitoes and houseflies. From 75 to 100 insects were used in each test.

Insecticide and Dosage	Tests Number	Knock-down in—		Kill in 24 Hours
		10 Min.	2 Hours	
		Per Cent		
Anopheles quadrimaculatus				
Median lethal:				
Pyrethrum[1]	18	30	83	68
DDT-pyrethrum	12	5	50	56
DDT-pyrethrum-motor oil	18	45	88	76
Recommended:				
Pyrethrum[1]	8	97	91	100
DDT-pyrethrins-motor oil	8	96	100	100
Musca domestica				
Median lethal:				
Pyrethrum[1]	18	9	0	8
DDT-pyrethrum	12	4	43	90
DDT-pyrethrum-motor oil	18	10	9	61
Recommended:				
Pyrethrum[1]	8	96	54	20
DDT-pyrethrins motor oil	8	97	97	100

[1] Standard formula containing 0.4 per cent of pyrethrins and 8 per cent of sesame oil in *Freon-12*.

Comparative tests with this pyrethrum-DDT formula (Table 3) showed that the desirable knock-down and lethal properties had been retained. This formula is relatively stable at low temperatures, and owing to the reduced concentration of auxiliary solvent and the presence of motor oil, it is relatively safe to use in the presence of plastics.[2]

SUMMARY.—Tests of pyrethrum and DDT aerosols were conducted against mosquitoes and houseflies under semipractical conditions. It was found that in order to obtain the necessary concentration of DDT in *Freon-12* an auxiliary solvent must be used, and that cyclohexanone was the most satisfactory.

On the basis of equal amounts of total solution the DDT aerosol was shown to be as toxic as the pyrethrum aerosol to adult anopheline mosquitoes and far more toxic to houseflies. The knock-down of both insects obtained with DDT, however, was relatively poor. The desirable knock-down properties of pyrethrum and the toxicity of DDT to houseflies were obtained by combining the two insecticides in an aerosol. The addition of motor oil made it possible to secure the desired effect at a reduced concentration of DDT and cyclohexanone.

[2] Most of the observations on the stability of the formula and the effect on plastics were made by L. D. Goodhue, and some of the biological tests were conducted by E. R. McGovran, in Bureau laboratories at Beltsville, Md.

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DDT as a Residual-Type Treatment for Control of Houseflies[1]

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In a previous note (Lindquist *et al.*, 1944) it was reported that the new insecticide DDT (2,2,-bis(*p*-chlorophenyl) 1,1,1-trichloroethane) possessed remarkable toxicity to houseflies, *Musca domestica* L., and when sprayed on surfaces the residual deposit remained toxic to flies for long periods. Wiesmann (1943) made the first report on the residual toxicity of this chemical to flies in stables. The present paper gives additional data on certain phases of the studies with DDT in experiments begun in February 1943 at the Orlando, Fla., laboratory of the Bureau of Entomology and Plant Quarantine.

METHODS.—Reared 5-day-old houseflies were exposed to surfaces that had been treated with various sprays containing known amounts of DDT, and the effectiveness was determined by observations on knock down and mortality. Flies were recorded as down when they were unable to crawl. Tests were conducted at room temperature, which ranged from 80° to 90° F., in the spring and summer, and at approximately 80° in the winter. The effect of temperature on the insecticidal action of DDT is important and will be discussed in another paper (see p. 261 this issue). From 80 to 100 flies were used in each exposure.

KILL ON SHORT EXPOSURE.—Since flies are on the wing much of the time during the day, the mortality that occurs when they are exposed to DDT-treated surfaces for short periods has an important bearing on control.

Flies were introduced and exposed for 1 or 5 minutes in small wooden boxes that had been sprayed at the rate of 125 mg. of DDT per square foot. They were then transferred to clean holding cages at 80° F. and provided with food and water. Records on knock down were made after 6 hours and on mortality after 24 and 48 hours. The data on two treatments—5

[1] This work was conducted under a transfer of funds, recommended by the Committee on Medical Research, from the Office of Scientific Research and Development to the Bureau of Entomology and Plant Quarantine.

per cent of DDT and 5 per cent of cyclohexanone in deodorized kerosene (*Deobase*), and 5 per cent of DDT in kerosene —are given in table 1. The 48-hour mortality records are not given, since they were practically the same as the 24-hour records, an indication that DDT possesses little or no delayed killing action on the second day after exposure. Knockdown after the 1-minute exposure is rather slow and seldom occurs within 2 hours. This is in contrast to continuous exposure, which in these boxes would knock all flies down in 30 to 100 minutes. Both spray formulas good gave results, but the DDT-cyclohexanone mixture in *Deobase* was slightly better throughout the 207-day test period.

Table 1.—Knockdown in 6 hours and kill in 24 hours of houseflies exposed for short periods in wooden boxes sprayed with 5 per cent DDT solutions.

Time Between Spraying and Exposure of Flies	DDT-Cyclohexanone in *Deobase*		DDT in Kerosene	
	Knockdown	Kill	Knockdown	Kill
Days	*Per Cent*	*Per Cent*	*Per Cent*	*Per Cent*
	1-Minute Exposures			
28	32	68	46	77
40	37	78	5	44
55	41	83	28	66
67	23	74	8	47
77	68	86	10	40
96	55	93	27	71
109	47	63	26	48
122	72	93	37	55
158	58	86	47	65
186	50	93	30	86
207	51	63	2	27
	5-Minute Exposures			
28	93	99	77	96
40	95	100	70	88
55	100	100	100	100
67	49	74	39	63
77	75	100	53	97
96	91	100	93	100
109	70	83	71	88
122	96	96	67	96
158	94	100	91	100
186	90	100	56	88
207	73	92	36	75

In another series of tests flies were exposed for 1 and 5 minutes in DDT-treated screen-wire cages. The solutions were applied to the screen with a brush at the rate of 100 mg. of DDT per square foot. As shown in table 2, dibutyl phthalate as a solvent of DDT did not give such good results as kerosene. This is in line with previous findings on other types of surfaces. These cages were used in dozens of demonstration tests and were handled frequently, which indicates that the residue will withstand considerable mechanical rubbing.

Four cages of synthetic screen cloth, which is used by the armed services, were treated with various DDT mixtures to determine their effect on the screen as well as their insecticidal efficiency. These cages were used in 1- and 5-minute exposure tests with a dosage of 100 mg. of DDT per square foot. The data are given in table 3. The DDT-talc-*Dreft* suspension gave the best results in both exposures. The particle size of the DDT-talc mixture averaged approximately 4 microns in diameter. None of the mixtures damaged the synthetic screen material.

Table 2.—Knockdown and kill of flies exposed for short periods in screen-wire cages painted with 10 per cent DDT solutions.

Time Between Treatment and Exposure of Flies	DDT in Dibutyl Phthalate		DDT-Cyclohexanone in Kerosene	
	Knockdown	Kill	Knockdown	Kill
Days	*Per Cent*	*Per Cent*	*Per Cent*	*Per Cent*
	1-Minute Exposures			
80	3	53	55	100
101	28	31	59	82
134	4	23	50	65
151	4	39	39	70
175	3	28	22	58
	5-Minute Exposures			
80	22	51	92	100
101	30	39	95	98
134	11	42	84	100
151	18	51	60	88
175	13	38	51	73

The effectiveness of DDT applied on screen cages suggests that the treatment of screen doors, windows, and porches of buildings may be an effective means of reducing fly populations. Although precise data are not available, preliminary field tests indicate that this method of treatment is effective in reducing the number of flies in milk rooms, screened garbage platforms, and army barracks and kitchens.

DDT ON PAINTED SURFACES.—A number of tests have shown that DDT in oil

Table 3.—Knockdown and kill of houseflies exposed for short periods in synthetic-screen cages treated with DDT in two solutions, an emulsion, and a suspension.

TIME BETWEEN SPRAYING AND EXPOSURE OF FLIES	5% DDT IN KEROSENE		5% DDT IN DIBUTYL PHTHALATE		5% DDT, 5% *Triton X-100*,[1] 15% XYLENE IN WATER		5% DDT, 5% TALC, 2% *Dreft*[2] IN WATER	
	Knock down	Kill	Knock down	Kill	Knock down	Kill	Knock down	Kill
Days	*Per Cent*	*Per Cent*	*Per Cent*	*Per Cent*	*Per Cent*	*Per Cent*	*Per Cent*	*Per Cent*
				1 Minute Exposures				
29	63	98	100	100	37	78	83	100
49	63	86	100	100	98	100	100	100
63	76	95	100	100	69	85	85	100
101	31	63	33	63	61	73	66	90
126	—	32	—	9	—	35	—	46
147	—	2	0	0	26	45	87	92
				5 Minute Exposures				
29	87	93	100	100	65	100	100	100
49	95	100	100	100	100	100	100	100
63	97	100	100	100	100	100	100	100
101	40	72	35	60	89	98	100	100
126	—	89	—	59	—	95	—	96
147	—	58	—	8	85	94	81	94

[1] An aralkyl polyether alcohol. [2] Sodium lauryl sulfate.

and other solutions is considerably less effective on surfaces that have been recently painted than on unpainted wood or old painted surfaces. In table 4 are given data comparing DDT in kerosene and in suspensions consisting of a mixture of DDT, talc, and a wetting agent when applied at the rate of 50 mg. of DDT per square foot to boxes of unpainted wood, boxes painted with an outside type of paint, and boxes painted with an inside paint. The boxes were painted 3 weeks prior to spraying. The outside paint contains more oil and does not dry so rapidly as the inside paint. DDT applied as a suspension was more effective on newly painted surfaces than when applied in kerosene, but because suspensions leave a visible deposit this treatment would probably be limited to barns and similar buildings.

DDT ON PLASTERED SURFACES.—To test the effectiveness of DDT on porous surfaces, small boxes were coated on the inside with plaster such as is used in dwellings and then sprayed with DDT in kerosene and in an emulsion at the rate of 25 mg. per square foot. Flies were introduced at intervals over a 200-day period. The time required for knockdown was about 100 minutes, which approximated the knockdown time on unpainted wood treated similarly.

Plastered rooms containing furniture were sprayed with DDT solutions and approximately 100 flies were released every few days during a 6-week period. The time required for all flies to be knocked down ranged from 1.5 to 4 hours, which was considerably longer than that required in the test boxes. It is believed that the fly's habit of being on the wing much of the time caused a slow knockdown. Moreover, in practical application the insecticide was not always evenly distributed over the surfaces and objects in a room.

DDT IN CALCIMINE.—The use of DDT in cold-water paints, such as calcimine, offers the possibility of combining a decorative and an insecticidal treatment for rooms. In table 5 are given results of a test in which 1 per cent of DDT was mixed with a calcimine and applied to a wooden box at the rate of 25 mg. of active material per square foot. Although this treatment did not give so fast a knockdown as the DDT in kerosene, it did cause complete mortality of flies, and other studies using higher concentrations of the insecticide in the calcimine indicate it to be more effective.

DDT-IMPREGNATED CLOTH.—The use of DDT-impregnated cloth instead of sticky flypaper strips appears to have a place in fly control. Strips of muslin 36 by 3 inches were dipped in DDT solutions at the rate of 2 to 3 grams of active ingredient per square foot. Some of the excess liquid was squeezed out by hand, and the cloth allowed to dry. The strips were hung

Table 4.—Time required to knock down flies introduced into unpainted and painted boxes, the inside of which had been sprayed with 5 per cent of DDT in kerosene and in water suspensions containing 5 per cent of talc and 2 per cent of a wetting agent.

Time After Spraying When Flies Were Introduced	Time Required to Knock Down All Flies in—		
	Unpainted box	Box painted with outside paint	Box painted with inside paint
Days	*Minutes*	*Minutes*	*Minutes*
Suspension Containing *Dreft*			
2	58	104[1]	90
33	184	*	69
49	116	*	116
64	141	*	86
103	151	*	168
127	320	*	200
Suspension Containing *Aresklene*[2]			
2	84	41	33
33	110	242	66
49	223	275	126
64	152	*	69
103	207	*	95
127	344	*	130
Suspension Containing *Duponol C*[3]			
2	81	38	48
33	100	74	81
49	133	141	140
64	65	193	112
103	94	300	139
127	236	385	200
Kerosene Solution			
2	38	*	*
33	43	*	*
49	32	*	*
64	26	*	*
103	50	*	*
127	129	*	*

[1] * indicates that many flies were not knocked down after 5 to 6 hours.
[2] Sodium disulfonate of dibutylphenylphenol.
[3] Sodium alkyl sulfates, principally lauryl.

from the ceiling of a fly-rearing room. Hundreds of flies were in the room in the late afternoon, but by morning nearly all were dead. The flies tended to rest on the muslin strips, thereby obtaining a toxic dose of insecticide. These strips were in effective use for 150 days. At the end of this time one strip was removed and made into a sack into which flies were introduced to test the speed of knock down. All flies were knocked down in 18 minutes. The relative effectiveness of different solutions has not been determined, but a mixture of 10 per cent of DDT plus 10 per cent of cyclohexanone in *Deobase* has proved satisfactory. A more highly volatile solvent than *Deobase* may be desirable.

Table 5.—Time required for complete knockdown of houseflies when introduced into wooden cages treated with 1 per cent of DDT in calcimine and in kerosene.

Time After Spraying When Flies Were Introduced	Time Required for Knockdown	
	DDT in Calcimine	DDT in Kerosene
Days	*Minutes*	*Minutes*
2	74	21
9	150	48
16	93	29
23	185	41
31	127	56
37	249	125
44	248	153

Since flies tend to rest on lamp cords, light wires, and strings, the treatment of such objects alone may be an effective way to reduce flies in restaurants and similar establishments.

DDT IN FURNITURE POLISH.—DDT has been dissolved in a furniture polish and used on tables in a mess hall. Reports indicate that the treatment is effective. In tests in boxes the mixture gave rapid knock down when used on unpainted wood, but poor results when rubbed on surfaces that had been lacquered 2 days previously.

SUMMARY.—In experiments on the toxicity of DDT spray residue, 5-day-old houseflies were introduced into various types of treated cages to determine the effect of short periods of exposure or the time required for knock down with continuous exposure.

When flies were exposed for 1 or 5 minutes and then transferred to clean cages for observations on knock down and mortality, boxes treated with 5 per cent of DDT plus 5 per cent of cyclohexanone in *Deobase* gave slightly better results over a 207-day period than those treated with 5 per cent of DDT in kerosene. When applied to screen-wire cages with a paint brush (at the rate of 100 mg. of DDT per square foot) 10 per cent of DDT gave better results when dissolved in kerosene than in dibutyl phthalate. In synthetic-screen cages treated with DDT in various mixtures, a water suspension containing 5 per cent of DDT, 5 per cent of talc, and 2 per cent of *Dreft* gave the best results over a period of 147 days. None of the

mixtures damaged the synthetic material. These tests suggest that DDT treatment of screen doors, windows, and porches may be an effective control measure.

When applied on painted surfaces the DDT suspension was more effective than DDT in kerosene, but since the treatment leaves a visible deposit its use might be limited to barns and similar structures.

Flies introduced into plastered boxes treated with DDT in kerosene were knocked down in about 100 minutes over a period of 200 days after treatment. This is about equal to the knockdown time obtained with the same treatment on unpainted wooden surfaces. The time of knockdown of flies introduced into rooms with plastered walls treated with DDT ranged from 1.5 to 4 hours over a 6-week period, but it is probable that the flies did not come in contact with the treated surfaces so frequently as when exposed in boxes.

One per cent of DDT in calcimine gave complete kill of flies, but the knockdown was not so rapid as in kerosene.

Strips of muslin treated with DDT and hung in the fly-rearing room gave almost complete kill of flies overnight, and remained effective for 150 days. This type of treatment might be applied to lamp cords, etc., where flies rest.

DDT dissolved in furniture polish and applied to mess hall tables is reported to have been effective. In boxes the mixture gave rapid knock down on unpainted wood, but poor results on newly lacquered surfaces.—8-6-44.

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Effect of Temperatures on Knockdown and Kill of Houseflies Exposed to DDT[1]

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Temperature has a marked influence on the speed of knock down and kill of some insects exposed to surfaces treated with DDT (2,2-bis(*p*-chlorophenyl) 1,1,1-trichloroethane). DDT will no doubt be used in many environments having a wide range of temperature, and biological data may vary accordingly. Because of its possible world-wide use in the control of many insects, the following experiments on temperature effects are presented here.

METHODS.—The technique employed consisted essentially in exposing houseflies, *Musca domestica* L., in small boxes or cages that had been treated with known dosages of 5 per cent DDT in kerosene, and recording the time required to effect complete knock down. When all the flies were down, the insects were divided and placed in clean untreated cages and held in chambers at various constant temperatures for observations on recovery and mortality. The relative humidity was maintained at 60 to 70 per cent. Insects were recorded as down when on their backs and unable to crawl. In some cases they were exposed in treated cages for only short periods (not long enough to cause knock down) before being transferred to the constant-temperature chambers. The test insects were about equally divided as to sex, but no distinction was made in recording mortality. However, males appeared to be somewhat easier to kill than females.

FLIES EXPOSED UNTIL KNOCKED DOWN.—Rapid recovery was observed when flies that had been knocked down in DDT-treated cages at 70° were transferred to a temperature of 80° to 100°. When returned to a temperature of 70°, all the flies were knocked down again in a few seconds, and when exposed again to a

[1] This work was conducted under a transfer of funds, recommended by the Committee on Medical Research, from the Office of Scientific Research and Development to the Bureau of Entomology and Plant Quarantine.

Table 1.—Effect of temperature on time required for knockdown of flies exposed in a box treated with DDT. 100 flies exposed at each temperature in each test.

Temperature	Time Required for—	
	50 Per Cent Knockdown	Complete Knockdown
°F.	*Minutes*	*Minutes*
50	14	46
65	16	46
75	20	61
85	26	73
95	35	104

higher temperature they again became active. This alternate changing of flies from one temperature to another, with consequent knock down and recovery, can be continued for some time before death results. This test has been repeated frequently in boxes and cages that have been treated with 10 to 100 mg. of DDT per square foot of surface.

Tests were also made to determine knockdown at various temperatures when flies were exposed continuously to DDT residue. These tests were conducted in a 0.1-cubic-foot wooden box treated 3 months previously with 50 mg. of DDT per square foot. As indicated in table 1, the time required for both 50 per cent and complete knockdown increased gradually as the temperature was increased. At first it was believed that the longer time required at high temperatures was due to greater activity of the flies so that they spent less time on the treated surface and thereby received smaller dosages than less active flies, but later observations showed that this was not the case.

Table 2.—Knockdown and kill of houseflies exposed at 65°–70° and 95° F. in DDT-treated boxes or cages until flies were moribund and then held in clean cages at different temperatures. One test with about 75 flies in each case.

Dosage of DDT	Time Between Treatment and Exposure	Temperature During Exposure	Time of Exposure for Complete Knockdown	Temperature After Transfer	Recovery After 1 Hour	Mortality After 24 Hours
Mg. per sq. ft.	*Days*	*°F.*	*Minutes*	*°F.*	*Per Cent*	*Per Cent*
In treated boxes:						
50	70	65	40	70	0	100
				90	50	100
				100	91	85
		95	97	70	0	100
				90	0	100
				100	17	97
	155	70	154	70	70	100
				80	0	100
				90	28	83
				100	48	61
		95	270	70	0	100
				80	0	100
				90	0	100
				100	10	100
In treated cages:						
100	160	70	55	70	0	100
				90	17	98
				100	11	98
		95	117	70	0	100
				100	2	100
				100	7	98
10	2	70	42	70	0	100
				90	22	98
				100	26	88
		95	98	70	0	100
				90	0	100
				100	3	100

The effect of temperature on mortality was studied by exposing flies in DDT-treated boxes or cages at various temperatures and, when knockdown was complete, transferring the flies to clean cages at different temperatures. Paired tests were made at two exposure temperatures, at 65° or 70° F. and at 95°, in cages that had been treated from 2 to 152 days previously with different dosages of DDT. In each test the flies exposed at each temperature were divided and held in the clean cages at 70°, 90°, and 100°. Records were made of flies that revived 1 hour after transfer, and mortality counts were recorded after 24 hours. The data on these tests are presented in table 2. No recovery of moribund flies occurred and 100 per cent mortality always was obtained when flies were held at 70°, irrespective of the temperature prevailing at the time of exposure. When held at 95° or 100°, some flies became active within 1 hour, and the 24-hour mortality usually was less than 100 per cent. Flies exposed to the higher temperatures showed slightly greater mortality apparently because of the longer time required for knock down and consequent longer contact with DDT.

Table 3.—Recovery and kill of flies exposed at 65° F. in a box treated with DDT, transferred to a chamber at 70° after knockdown, and after various intervals removed to another chamber at 100°. 100 flies in each test.

TIME FLIES HELD AT 70° F.	RECOVERY AFTER 1 HOUR AT 100° F.	KILL AFTER 24 HOURS AT 100° F.
Hours	*Per Cent*	*Per Cent*
0	97	50
1	29	87
2	17	94
3	14	96
4	7	98
5	6	97
6	2	98
24	0	100

In another experiment flies were exposed at 65° F. in a box treated 87 days previously with 50 mg. of DDT per square foot. When knockdown was complete (after 63 minutes), the flies were transferred to eight clean cages, seven of which were placed in a chamber at 70°. At hourly intervals for 6 hours and after 24 hours one cage was removed from this chamber and placed in another chamber at 100° for 24 hours. The eighth cage was placed in the 100° chamber immediately after knockdown. As shown in table 3, recovery of flies after removal from 70° was progressively less, and mortality was greater, the longer they remained at this temperature. It is indeed remarkable that some of the flies recovered at 100° after being completely inactive for several hours at 70°. Replications of this test show the same general trend.

Table 4.—Knockdown and kill of flies exposed in DDT-treated cages for short periods and then transferred to clean cages held at different temperatures. Average of 4 tests, each with about 50 flies.

EXPOSURE TIME	TEMPERATURE AT WHICH FLIES WERE HELD AFTER EXPOSURE	KNOCKDOWN		KILL IN 24 HOURS
		1 Hour	6 Hours	
Minutes	*°F.*	*Per Cent*	*Per Cent*	*Per Cent*
	Exposure Temperature 70° F.			
5	70	77	81	99
	80	16	60	71
	90	4	42	53
	100	1	28	28
10	70	89	98	100
	80	57	74	83
	90	4	50	55
	100	2	26	37
	Exposure Temperature 95° F.			
5	70	69	86	97
	80	92	64	79
	90	4	42	52
	100	1	18	23
10	70	81	99	100
	80	40	70	85
	90	4	48	54
	100	0	23	54

FLIES EXPOSED FOR SHORT PERIODS.—The effect of exposing flies for short periods and then transferring them to different temperatures is shown in table 4. The flies were exposed for 5 or 10 minutes in small screen cages treated 25 days previously with 200 mg. of DDT. In these tests the exposure time was not sufficient to cause knockdown during the exposure period. It will be observed that after 1 hour the flies kept at 70° showed a knockdown of 69 to 89 per cent while those kept at 100° showed from 0 to 2 per cent down. The corresponding 24-hour mortalities were 97 to 100 and 23 to 54 per cent. The mortality decreased gradually between 70° and 100°.

Immediately after a short exposure to DDT, the flies became somewhat excited. Walking was accelerated and cleaning of the wings and feet increased. The typical tremors began after 20 to 40 minutes and

continued until the flies became incapacitated. It was also observed that flies exposed to DDT until they showed only slight excitation were rapidly thrown into tremors when placed at the low temperature of 40° to 50° F.

COMPARATIVE TESTS WITH PYRETHRUM.—In order to compare the performance of DDT and pyrethrum, a few tests were made in pyrethrum-treated cages. Flies were exposed in cages treated several days previously with 200 mg. of pyrethrins, per square foot, until all were knocked down, and then transferred to clean cages at a different temperature (Table 5).

Table 5.—Recovery and mortality of houseflies 24 hours after exposure in pyrethrum-treated cages until knocked down and then transferred to clean cages and held at different constant temperatures. Average of 6 tests, each involving about 50 flies.

Average Knock-down Time	Temperature at Which Flies Were Held After Transfer	Recovery		Mortality After 24 Hours
		After 1 Hour	After 6 Hours	
Minutes	*°F.*	*Per Cent*	*Per Cent*	*Per Cent*
	Exposure Temperature 70° F.			
40	70	12	81	6
	80	60	81	12
	90	82	89	31
	100	74	72	34
	Exposure Temperature 95° F.			
22	70	0	24	51
	80	2	46	49
	90	7	56	61
	100	4	25	78

Pyrethrum caused knockdown in 2 to 5 minutes 3 to 5 days after it was applied to the cages, but lost its effectiveness rapidly and gave no knockdown after about 10 days. Although the knockdown time varied considerably, it averaged 40 minutes when exposure was made at 70° and 22 minutes at 95°, which is exactly the reverse of the performance with DDT. Moreover, recovery was greater at the lower holding temperatures, which also is the opposite of DDT. There was also greater mortality after 24 hours when exposure was made at 95° than at 70°, irrespective of the holding temperatures.

SUMMARY AND CONCLUSION.—Houseflies were exposed at several temperatures to DDT-treated surfaces for varying lengths of time and, after exposure, held in clean untreated containers at different temperatures.

Houseflies exposed continuously to DDT-treated surfaces were knocked down much more quickly at 70° F. than at higher temperatures.

When flies were exposed at 70° and 95° F. for 5 or 10 minutes (not long enough to cause knock down), in cages previously treated with DDT, and then held at different constant temperatures for 24 hours, very little difference in mortality occurred between flies exposed at the two temperatures. However, the flies always showed a higher mortality at the lower holding temperatures, irrespective of the exposure temperatures.

Flies exposed to the residue of pyrethrum in treated cages showed a faster knock down at 95° F. than at 70°, and a greater recovery when held at the lower temperature. Furthermore, greater mortality occurred after 24 hours when exposure was made at 95° than at 70°, irrespective of holding temperature. In all respects these results are the reverse of those obtained with DDT.

These results indicate that temperature may influence the effectiveness of DDT against a given species of insect in various parts of the world. However, deposits of DDT are effective against houseflies over a wide range of temperatures.—9-11-44.

ORIENTAL FRUIT MOTH QUARANTINES EXTENDED

Recent revisions of the oriental fruit moth quarantines of Arizona, California, Idaho, and Washington extended the regulated areas to include the entire State of Idaho and the counties in Colorado and Utah that were found infested in the 1944 survey. *Cotoneaster pannosa* and *Photinia serrulata* are added to the list of hosts. The limitation as to the period during which nursery stock may be treated for entry has been removed, and the revised quarantines specify that packing material which might carry the moths is prohibited in nursery-stock shipments.

SET OF THE JOURNAL GIVEN TO THE ASSOCIATION

Mr. James F. Townsend, of New Haven, Conn., has donated his set of the *Journal of Economic Entomology* to the Association. Mr. Townsend was elected a member of the Association at the annual meeting held at Columbia University in New York City in December, 1928. As a result the set of the Journal which he has donated contains volumes from No. 22 to No. 37, and makes a most welcome addition to our reserve stock which is certain to be insufficient to meet post-war demands. We will assume the privilege of extending the thanks of the Association to Mr. Townsend.

DDT and Other Insecticides as Residual-Type Treatments to Kill Bedbugs

A. H. Madden, Arthur W. Lindquist, and E. F. Knipling,[1] *U.S.D.A., Agr. Res. Adm., Bureau of Entomology and Plant Quarantine*

Since October 1942 investigations have been in progress at a laboratory of the Bureau of Entomology and Plant Quarantine to develop a method of controlling bedbugs, *Cimex* spp., that would be particularly suited to military requirements. Fumigation with hydrocyanic acid is not only expensive but in the hands of unskilled personnel is considered hazardous to human life, and ordinary spray treatments must be applied directly to the bugs for effective control. Moreover, neither of these methods has a lasting effect, and the treatment must therefore be repeated as frequently as reinfestation occurs. To control bedbugs that remain hidden during application of treatment and to prevent reinfestation over a reasonable length of time, an insecticide must possess residual toxic properties of considerable duration. These investigations were undertaken for the purpose of discovering such a material. In a previous note (Madden, *et al.* 1944) the writers presented a brief account of the work. The results are given in detail in this paper.

A mixed culture of the common bedbug, *Cimex lectularius* L., and the tropical bedbug, *C. hemipterus* F., was used. However, tests conducted against each species separately indicate that there is no particular species resistance to insecticides applied in the manner described herein.

Laboratory Investigations.—*Jar tests.* To test the residual properties of an insecticide it was necessary to devise some method other than the usual practice of applying it directly to the insect. The method finally adopted was to apply the material to both sides of a circular woolen pad 2⅝ inches in diameter, and about an hour later to drop the pad into a half-pint fruit jar containing five normal adult bugs. After 15 minutes the pad was removed and the bugs were held in the jar for later mortality counts. Most of these tests were conducted at approximately 80° F. This method afforded a rapid and easy means of checking the residual action of a large number of potential bedbug insecticides.

In these initial experiments the materials were tested both in dust and spray form. Approximately 1500 tests were completed and about 100 materials evaluated. Dusts prepared by impregnating the carrier with the insecticide were applied to the pads by shaking through a fine-mesh screen, using 0.08 gram per pad, and then rubbing into the cloth. Sprays were applied with a small hand atomizer, using 0.25 ml. per pad. Mortality counts were made after 24 hours.

Results obtained with materials applied in dust form are summarized in table 1. Pyrethrum and the new insecticide DDT (2,2-bis(*p*-chlorophenyl)-1,1,-trichloroethane) were the only materials which gave satisfactory kill. It will be noted that a number of the common insecticides failed to show satisfactory residual action by this method of testing.

Tests were continued with pyrethrum and DDT to determine the duration of residual toxicity. The same method was followed except that fresh lots of bugs were exposed at intervals to the same treated pads until mortality with the best materials dropped below 100 per cent. The results are shown in table 2. The DDT dusts gave complete mortality up to 49 days after application, whereas the pyrethrum dusts were less effective and gave more erratic results over the same period.

There are obvious objections to the unsightliness of an insecticide applied as a dust for the treatment of military quarters. For this reason the main effort was directed toward testing sprays. The results obtained with sprays when tested in the laboratory shortly after application are summarized in table 3. Many of the materials tested in dust form were included in the spray tests, and a large number that were unsatisfactory as dusts gave good results in this form. As in the

[1] This work was conducted under a transfer of funds, recommended by the Committee on Medical Research, from the Office of Scientific Research and Development to the Bureau of Entomology and Plant Quarantine. Acknowledgment is made of the advice and assistance of Howard A. Jones on the chemical phases of the problem and of the assistance of John Beidler and Sidney Webb in conducting the tests and maintaining the colony. Some of the compounds used were prepared by the Division of Insecticide Investigations of the Bureau.

Table 1.—Residual toxicity of various dusts to bedbugs when tested by the jar method; 5 adult bugs used in each test.

MATERIAL[1]	TESTS	MORTALITY AFTER 24 HOURS
	Number	*Per Cent*
DDT 5%	3	100
DDT 5% in *Inert C* (a clay)	3	100
Pyrethrins 0.2%	15	99
Pyrethrins 0.2%+2,4-dinitroanisole 2%	15	92
DDT 5%+mineral oil 5%[2] in *Inert C*	3	87
Pyrethrins 0.3%+N-butyl-3,6-methylene-4-cyclohexene-1,2-dicarboximide 4%+2,4-dinitroanisole 4%+*Phenol S* (isopropyl cresols, byproduct of thymol manufacture) 0.25%	12	80
4,6-Dinitro-o-cresol 10%[3]	12	78
Pyrethrins 0.2% in sulfur	6	67
2-Chlorofluorene 20%	6	54
N-n-Amyl-3,6-methylene-4-cyclohexene-1,2-dicarboximide 5%+*IN-930* (N-isobutylundecylenamide) 2%	3	53
N-Butyl-3,6-methylene-4-cyclohexene-1,2-dicarboximide 5%+*IN-930* 2%	3	53
Tetramethylthiuram monosulfide 10%	12	40
N-Butyl-3,6-methylene-4-cyclohexene-1,2-dicarboximide 5%	12	35
Pyrethrins 0.01%+extract of prickly-ash bark 1%	3	33
6-Cyclohexyl-2,4-dinitrophenol 10%	9	27
2,4-Dinitroanisole 5%+*IN-930* 2%	12	22
2-Methyl-4-phenylthiazole 10%	12	25
Tetramethylthiuram disulfide 10%	3	20
alpha, beta-Dibromo-beta-nitroethylbenzene 5%	3	20
2,4-Dinitroanisole 5%	12	19
N-n-Amyl-3,6-methylene-4-cyclohexene-1,2-dicarboximide 5%	9	18
Nicotine zinc thiocyanate 25%	6	17
Valone (isovaleryl-1,3-indanedione) 5%	6	17
Sulfur, wettable, 325-mesh, 100%	9	16
Thanite (isobornyl thiocyanoacetate) 5% in boric acid	3	13
6-Cyclohexyl-2,4-dinitrophenol 1%	3	13
6-Nitrotrichlorotoluene 10%	12	12
Sesamin 100%	3	10
2,2′-Bipyridine 1%	3	10
Extract of prickly-ash bark 1%	3	7
Lorol 2-thiazolinyl sulfide 10%	12	5
N-Isobutylcapramide 5%+*IN-930* 2%	12	5
Azoxybenzene 10%	9	4
Valone 5%+*IN-930* 2%	9	3
IN-5052 (2′Hydroxy-2,4,4,4′,7-pentamethylflavan 10%)	12	2
N-Isobutylcapramide 5%	9	2
Phenyl-l-naphthylamine 10%	9	2
N-Isobutyllauramide 5%	9	0
N-Isobutyllauramide 5%+*IN-930* 2%	3	0
Crystox (a synthetic fly-spray toxicant) 100%	6	0
2,4-Dinitrophenetole 5%	3	0
Mitin FF concentrate (sodium salt of 5-chloro-2-[4-chloro-2-(3,4-dichlorophenylureylene)phenoxy]benzenesulfonic acid) 5%	3	0
8-Quinolinol 5%	3	0
4-Chlorobiphenyl 5%	3	0
2,2′-Bipyridine 1%+*IN-930* 2%	3	0
Phenoxathiin 1%	3	0
Phenoxathiin 1%+*IN-930* 2%	3	0
Rotenone 1%	3	0
Rotenone 0.5%	3	0
Rotenone 0.25%	3	0
Sodium fluoride 100%	3	0
Tobacco dust 100%	3	0
IN-930 5%	3	0

[1] Where pure materials were not used, pyrophyllite was the diluent unless otherwise noted. The particle size of DDT ranged from 5 to 8 microns.
[2] Mineral oil used in these investigations had a viscosity of 75–80 seconds Saybolt at 100° F.
[3] Leaves an objectionable yellow stain.

Table 2.—Duration of residual toxicity to bedbugs of various pyrethrum and DDT dust treatments when tested by the jar method. Average of 3 tests of each material for each exposure interval; 5 adult bugs used in each test.

Time Between Dusting and Exposure of Bugs, Days	Per Cent Mortality After 96 Hours					
	Pyrethrum-Pyrophyllite Dusts			DDT (5%) Dusts in—		
	Pyrethrins 0.3%+N-Butyl-3, 6-Methylene-4-Cyclohexene-1,2-Dicarboximide 4% +2,4-Dinitroanisole 4%+*Phenol S* 0.25%	Pyrethrins 0.2%+2,4-Dinitroanisole 2%	Pyrethrins 0.2%	Pyrophyllite	*Inert C*	*Inert C* +Mineral Oil 5%
1	100	100	100	100	100	100
2	100	100	60	100	100	100
3	47	47	60	100	100	100
4	93	40	7	100	100	100
7	40	20	7	100	100	100
8	80	88	13	100	100	100
9	87	88	67	100	100	100
14	100	93	73	100	100	100
21	53	7	20	100	100	100
28	47	27	27	100	100	100
49	93	87	—	100	100	100
56	0	0	0	53	40	87

dust tests, DDT was among the materials giving 100 per cent mortality, while some of the ordinary insecticides were not very effective. Deodorized kerosene (*Deobase*), which was used as the diluent or solvent in most cases, gave practically no kill alone.

Tests to determine the persistence of toxicity were conducted with sprays giving a mortality of 50 per cent or more, and all the materials except DDT were eliminated 1 day after application. Both 1 and 5 per cent concentrations of DDT in *Deobase* gave 100 per cent mortality for 39 days.

Preliminary tests of four analogs of DDT (prepared by the Division of Insecticide Investigations) at concentrations of 5 per cent in *Deobase* gave the following mortalities at the end of 28 days: 2,2-di-p-tolyl-1,1,1-trichloroethane, 100 percent; 2,2-di-p-anisyl-1,1,1-trichloroethane, 100 per cent; 2,2-bis(p-bromophenyl)-1,1-dichloroethylene, 90 per cent; and 2,2-bis (p-chlorophenyl)-1,1-dichloroethylene, 60 per cent. In further tests with the two most promising of these materials, 5 per cent of 2,2-di-p-anisyl-1,1,1-trichloroethane gave a high mortality up to 39 days after application and appears worthy of further consideration.

CAGE TESTS.—In order to evaluate bedbug treatments under simulated natural conditions where closer observations are possible than in natural infestations, a method was developed utilizing cages treated with various insecticides. In the first of these tests the spray was applied with a hand atomizer over the entire inner surface of glass-topped wooden cages 19 by 14 by 14.5 inches. Lots of 10 adult bugs were released in each cage at intervals after spraying and exposed for 48 hours. At the end of this period mortality counts were made. Five per cent of DDT in kerosene applied at the rate of 25 mg. of toxicant per square foot gave 100 per cent mortality up to 38 days after treatment, while the same concentration plus 10 per cent of benzyl benzoate in *Deobase*, at the same dosage, gave 100 per cent mortality up to 48 days after treatment. An aqueous emulsion containing 5 per cent of DDT, 10 per cent of benzyl benzoate, 5 per cent of *Vatsol OT*, and 10 per cent of *Deobase* applied at the rate of 25 mg. of DDT per square foot, gave 100 per cent mortality up to 32 days after treatment. Pyrethrum was not tested in these cages.

Natural conditions were simulated more closely by utilizing 30 by 30 by 31 inch cages with glass sides and plywood top and bottom with inner demountable walls of unpainted wood extending halfway up the sides, each containing a small mattress. The material to be tested was sprayed on the walls and floor of the cage

Table 3.—Residual toxicity of various sprays to bedbugs when tested by the jar method.

MATERIAL[1]	TESTS	MORTALITY AFTER 24 HOURS
	Number	*Per Cent*
DDT 2%	3	100
DDT 5%+dimethyl phthalate 28%+acetone 67%	3	100
DDT 20% in acetone	3	100
DDT 20% in benzyl benzoate	3	100
Valone 10%[2]	18	100
Pyrethrins 0.05%+N-Butyl 3,6-methylene-4-cyclohexene-1,2-dicarboximide 5%	6	100
N-Amyl-3,6-methylene-4-cyclohexene-1,2-dicarboximide 5%	9	98
DDT 10% in cyclohexanone	9	98
m-Cresol 100%	9	98
Pyrethrins 0.5%+N,N-diethylcinnanamide 2%	20	96
DDT 1%+*IN-930* 2%	12	95
Pyrethrins 0.5%+N-isobutylcapramide 2%	20	92
Pyrethrins 0.5%+N,N-diethylpiperonylamide 2%	20	92
Pyrethrins 0.05%+N-Butyl 3,6-methylene-4-cyclohexene-1,2-dicarboximide 2%+*IN-930* 2%	20	92
N-Butyl-3,6-methylene-4-cyclohexene-1,2-dicarboximide 5%	21	91
Pyrethrins 0.05%+sesame oil 2%	20	90
DDT 1%	6	90
Pyrethrins 0.05%+N-Butyl 3,6-methylene-4-cyclohexene-1,2-dicarboximide 2%	20	87
Pyrethrins 0.05%+N-isobutyllauramide 2%	20	86
Valone 5%	12	85
N-Butyl-3,6-methylene-4-cyclohexene-1,2-dicarboximide 2%+*IN-930* 2%	20	80
o-Cresol 100%	9	80
Safrole 100%	9	80
Thanite 5%	5	80
Bis-ethylxanthogen 20%	5	80
N-Butyl-3,6-methylene-4-cyclohexene-1,2-dicarboximide 5% in mineral oil	6	77
N-Butyl-3,6-methylene-4-cyclohexene-1,2-dicarboximide 2%+N-isobutylcapramide 2%	20	75
Crystax 10%	18	71
N-Butyl-3,6-methylene-4-cyclohexene-1,2-dicarboximide 2%+sesame oil 2%	20	71
N-Butyl-3,6-methylene-4-cyclohexene-1,2-dicarboximide 2%	20	70
Lorol rhodanate (lauryl thiocyanate) 5%	18	70
Azoxybenzene 10%	15	69
Diphenylamine 10%	20	65
Annol[3] 100%	9	53
Thanite 5% in mineral oil	5	52
Lethane 384 Special 5%[4]	21	51
Cyclohexanone 100%	12	50
Lethane 384 Special 2.5%+*Crystox* 2.5%	9	47
N-Butyl-3,6-methylene-4-cyclohexene-1,2-dicarboximide 5% in *Annol*	3	47
alpha, beta-Dibromoethylbenzene 5%	9	40
Valone 5% in dimethyl phthalate	6	40
Dowcide 5 (3-bromo-4-hydroxybiphenyl) 2.5%	6	40
Tetralin 100%	6	40
p-Cresol 100%	3	33
o-Methoxybiphenyl 5%	9	29
Dimethyl phthalate 100%	9	20
Benzyl *Cellosolve* 100%	3	20
2-Ethylhexanediol-1,3 25% in Stoddard solvent	3	20
Benzyl benzoate 100%	3	13
o-Chlorophenyl p-toluenesulfonate 100%	3	13
o-Dichlorobenzene 5%	3	13
o-Dichlorobenzene 100%	3	13
2,4-Dinitrophenyl n-propyl ether 100%	3	13
N-Butyl-3,6-methylene-4-cyclohexene-1,2-dicarboximide 5% in dimethyl phthalate	6	10
Decalin 100%	6	10
Acetophenone 100%	3	10
Nicotine (as nicotine sulfate) 1%+lactic acid 1.5%	9	9
Tetrahydrofurfuryl alcohol 100%	3	7
Carbon tetrachloride 100%	3	7
Indalone (n-butyl mesityl oxide oxalate) 25% in Stoddard solvent	3	7
2'-Hydroxy-2,4,4,4',7-pentamethylflavan 10%	9	4
IN-930 10%	9	4

Table 3.—Continued.

Deobase 100%	6	3
2-Nitropropane 100%	3	0
Aroclor 1248 5%[3]	3	0
Dibutoxyethyl phthalate 100%	3	0
Di(beta-butoxyethyl)phthalate 100%	3	0
Dibutyl phthalate 100%	3	0
Phenyl *Cellosolve* 100%	3	0
Kerosene emulsion 33%	3	0
Nopco 1666 5%[3]	3	0
Nopco 1216-K 5%[3]	3	0
Vatsol OT (dioctyl sodium sulfosuccinate) 5%	3	0
2,2-Bis(p-bromophenyl)1,1,1-trichloroethane 10%	3	0
o-Cresol 10% in cyclohexanone	3	0

[1] Material diluted with *Deobase* unless otherwise noted.
[2] Fumes extremely irritating to nose and throat.
[3] No adequate chemical description available.
[4] A mixture of 3 parts of beta-thiocyanoethyl esters of aliphatic acids and 1 part of beta-butoxy-beta-thiocyanodiethyl ether.

and on the mattress, the upper portion of the cage being left untreated. Ten bugs were released in each cage at intervals of several days, and after 48 hours' exposure mortality counts were made.

In the first tests in this type of cage the duration of residual toxicity of a 20 per cent DDT spray applied at the rate of 100 mg. of DDT per square foot was compared with that of 0.5 per cent pyrethrins spray applied at the rate of 2.5 mg. of pyrethrins per square foot. The results are presented in table 4. Although slight fluctuations in kill occurred throughout the period, it will be noted that the DDT sprays gave 100 per cent kill as long as 69 to 78 days after treatment. The pyrethrum spray, however, gave a rather low kill even 9 days after application, and its effectiveness practically disappeared by the 29th day, although subsequently the kill increased somewhat. Of interest is the fact that one of the DDT-treated cages, which had been thoroughly scrubbed with soap and water 8 days after the material was applied, gave 100 per cent mortality 78 days after treatment. It appears therefore that the toxic residue is very difficult to remove.

A second series of tests in the same type of cages, comparing the duration of residual toxicity of DDT at various dosages and in different solutions, is summarized in table 5. The aqueous emulsion gave the longest period of high effectiveness, followed by DDT in kerosene and DDT plus cyclohexanone in *Deobase*, when the last solution was applied at the rate of 100 mg. of DDT per square foot, the period was reduced to 136 days. Mortality fluctuated

Table 4.—Duration of residual toxicity of DDT and pyrethrins to bedbugs exposed for 48 hours in 20-cubic-foot cages at intervals after cages were sprayed.

Time Between Spraying of Cage and Exposure of Bugs, Days	Per Cent Mortality			
	DDT 20% in o-Dichlorobenzene		DDT 20% +o-Dichlorobenzene 40% +*Deobase* 40%	Pyrethrins 0.5% +*IN-930* 2% in *Deobase*
	Cage Not Washed	Cage Washed		
9	100	—	100	60
13	100	100	100	80
17	100	90	100	40
22	100	—	—	60
24	—	80	80	—
29	100	—	—	10
31	—	90	100	—
36	90	90	100	20
42	100	—	—	10
46	—	80	100	—
50	80	—	—	0
53	—	100	100	—
57	100	—	—	20
60	—	60	100	—
64	100	—	—	10
69	—	100	100	—
73	100	—	—	20
78	—	100	90	—
82	70	—	—	60
97	—	70	80	—
101	90	—	—	40
110	—	60	70	—
114	80	—	—	10
129	20	40	60	10

Table 5.—Duration of residual toxicity of various DDT sprays to bedbugs exposed for 48 hours in large cages at intervals after cages were sprayed.

Treatment	Dosage of DDT	Time After Treatment That 100 Per Cent Mortality Was Obtained
	Mg. per square foot	*Days*
DDT 5% in kerosene	100	171
DDT 10% +cyclohexanone 10% in *Deobase*	150	171
	100	136
DDT 20%+o-dichlorobenzene 40%+*Deobase* 40%	100	164
DDT 5% aqueous suspension[1]	100	157
DDT 5% aqueous emulsion[2]	150	191

[1] 10 gm. of a 1:1 DDT-talc mixture+2 gm. of sodium lauryl sulfate diluted with water to 100 ml.
[2] DDT 25%+*Wetsit* (alkylated aromatic sulfonate) 25%+xylene 50% diluted 1 to 4 with water.

between 80 and 100 per cent, although the latter was recorded more frequently. This fluctuation may have been due to migration of a number of bugs to the untreated portion of the cages, where they escaped exposure to a lethal dosage of DDT. This supposition is strengthened by the fact that lower kills were recorded during warm periods when the bugs were most active. However, a limited number of recent tests indicate that DDT gives a better kill of bed bugs at low temperatures than at higher temperatures.

Sullivan *et al.* (1942) report that preliminary tests with pyrethrins dispersed as aerosols by means of a liquified gas gave a high mortality of bedbugs at twice the dosage required to kill mosquitoes. Creighton (1943) also states that aerosol applications at the rate of 30 mg. of "pyrethrum" (probably meaning pyrethrins) per 1000 cubic feet will give control. Initial tests conducted by the writers with both pyrethrum and DDT aerosols indicate that such treatments might be relatively ineffective in practice, since bedbugs concealed in crevices and under cloth are almost completely protected from aerosols. The results of a number of later tests, however, show that DDT applied in this manner leaves a durable and effective toxic residue. In one test in which 6.5 per cent of DDT plus 12.5 per cent of o-dichlorobenzene plus 2.5 per cent of oleic acid, with methyl chloride as the propellent gas, was applied at the rate of 100 mg. of DDT per square foot, 100 per cent kill was obtained after 54 days and 60 per cent after 129 days.

TESTS UNDER PRACTICAL CONDITIONS.—To determine the effectiveness of DDT spray residue under practical conditions, tests were conducted in a number of infested houses. In these tests the spray was applied to the bedstead, springs, and mattress, and to the floors and walls around the bed. At weekly intervals during the course of the tests 25 adult bedbugs were released on each bed and mortality counts made at the end of 48 hours. The temperatures under which these tests were made ranged from about 40° to 95° F.

In all cases the original infestation was eradicated, and reinfestation from natural sources prevented. The results of a number of these tests are presented in table 6. The longest record of 100 per cent mortality was obtained with the mixture of

Table 6.—Duration of toxicity of DDT spray residue to bedbugs under practical conditions. Spray applied to bedsteads, springs, mattresses, and floor and walls near beds.

TREATMENT	AMOUNT OF SPRAY APPLIED	TIME AFTER TREATMENT THAT 100 PER CENT MORTALITY WAS OBTAINED
	Ml. per square foot	*Days*
DDT 20%+o-dichlorobenzene 40%+*Deobase* 40%	140	320
DDT 5%, aqueous emulsion[1]	250	102
DDT 10%+cyclohexanone 5% in kerosene	250	104[2]
DDT 5% in kerosene	195	64[2]
	250	84[2]

[1] DDT 25%+*Wetsit* 25%+xylene 50%, 1 part to 4 parts of water.
[2] Tests discontinued.

DDT, o-dichlorobenzene, and *Deobase*. However, some of the other treatments probably would have been effective for several months if the tests had not been terminated before the entire period of effectiveness could be determined.

Application of 5 per cent of DDT in kerosene to several infested army barracks in the Orlando area has given complete protection for about 6 months. A large-scale test is now being conducted in the same area under the direction of Lt. Col. J. Q. A. Daniels, M.C., Medical Inspector, Air Surgeon's Branch, Army Air Forces Tactical Center. In this test a total of 150 barracks and 15 warehouses, including 8466 beds and 8352 mattresses, have been treated, the material being applied to the beds, mattresses, pillows, floors, and walls by a trained crew of enlisted men using paint-spraying equipment and a gasoline-powered air compresser. A total of 1606 quarts of 5 per cent DDT in kerosene and 112 quarts of 7 per cent DDT plus 7 per cent cyclohexanone in kerosene, or approximately 14 quarts per 70-man barracks, have been used. A survey before treatment showed that the infestation ranged from light to heavy, but during the 7 months since the test was begun no bedbugs have been recorded in any of the treated barracks.

In preparing DDT sprays a number of solvents may be used, but from the practical standpoint, including availability, cost, reduction of fire hazard, and nonstaining properties, kerosene is considered to be the most satisfactory. Only 5 per cent of DDT will dissolve in this solvent, but under both laboratory and practical

conditions this concentration has proved to be effective for several months. The solution should be applied thoroughly as a wet spray (droplets, not a mist) so as to leave a deposit of at least 100 mg. of DDT per square foot. This is extremely important, since if such a deposit is not obtained the effectiveness of the treatment will be unsatisfactory and of short duration. DDT is somewhat slow in its action against bedbugs, and complete kill of those coming in contact with the deposit should not be expected until about 48 hours after exposure.

Although DDT is comparatively safe toxicologically, as a special precaution the operator should wear a repirator and rubber gloves when applying large quantities of the spray, and avoid allowing oil solutions to have contact with the body for long periods.

SUMMARY.—Investigations were undertaken to find a material for the control of bedbugs, *Cimex* spp., that would retain its toxic properties for some time after treatment. Such a material would provide a method of control that would be superior to ordinary spraying or fumigation, since one application would give the desired protection. Laboratory tests of a large number of organic compounds, applied both as dusts and as sprays, showed DDT and pyrethrum to be the only satisfactory insecticides for this type of treatment, and tests with these two materials for residual toxicity indicated DDT to be much superior. Of four analogs of DDT tested, 5 per cent of 2,2-di-p-anisyl-1,1,1-trichloroethane gave a high mortality up to 39 days. Under cage conditions sprays containing 20 per cent of DDT gave complete mortality up to 78 days after application, whereas a pyrethrum spray containing 0.5 per cent of pyrethrins gave a low kill after 9 days. In later tests the best results were obtained with a 5 per cent DDT aqueous suspension, which gave complete mortality up to 191 days.

An aerosol consisting of 6.5 per cent of DDT plus 12.5 per cent of o-dichlorobenzene in methyl chloride, applied at the rate of 100 mg. of DDT per square foot, gave 100 per cent kill for 54 days.

In practical tests conducted in infested houses and army barracks, sprays containing 5 to 20 per cent of DDT remained highly effective for 5 to 11 months.

Of the various spray mixtures tested, 5 per cent of DDT in kerosene is considered the most satisfactory for practical reasons. This solution should be applied as a wet spray so as to leave a deposit of at least 100 mg. of DDT per square foot. Complete kill of bedbugs coming in contact with the deposit may not occur until about 48 hours after exposure.—8-6-44.

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EUROPEAN CORN BORER QUARANTINES CHANGED

The States of Arkansas and Louisiana, early in 1945, revoked their quarantines pertaining to the European corn borer, and Arizona, California, and Tennessee recently revised their regulations pertaining to the pest. The action of these 3 states is uniform only as to the addition of 3 Tennessee counties to the regulated area. Arizona's revised quarantine adds the entire states of Kansas and Minnesota to the regulated area; California's order added only one Kansas county and 2 in Minnesota, while the Tennessee regulation placed no restrictions against Kansas products and designated 16 Minnesota counties as infested.

DDT Sprays to Control Codling Moth in Maryland

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A block of trees in an apple orchard located at Cordova, Maryland was selected for tests against codling moth with DDT and compared with the standard spray of lead arsenate, oil and nicotine. The DDT used was *Gesarol AK20* spray which contained 20 per cent *GNB-A*-DDT supplied by the Geigy Company, Inc., of New York. The amount of material listed in the sprays represents pounds of actual DDT. The block consisted of five acres of ten-year old trees of Stayman Winesap, Red Starking and Grimes Golden, which were partly surrounded by a block of old trees that for the past several years have had from 50 to 80 per cent of the fruit injured by codling moth, even though a heavy spray program consisting of lead arsenate, nicotine and oil had been practiced. The block selected for the tests had a 40 per cent crop in 1943 which showed close to 100 per cent of the fruit injured by codling moth with about 80 per cent wormy. In that year the entire orchard received seven lead arsenate sprays, three of which had one pint of nicotine sulfate and one gallon of summer oil added per 100 gallons.

Eight rows, each of which contained 12 trees, six Stayman, three Red Starking and three Grimes were selected for the experiment. Records were taken on all the apples, including drops from one tree of each variety from each row: 34,321 Stayman, 18,690 Red Starking and 38,770 Grimes, a total of 91,790. All sprays were applied by the grower with a machine that gave about 500 pounds pressure; about twelve gallons of spray were applied per tree per treatment. Lead arsenate was used at the rate of 3 pounds per 100 gallons of spray unless otherwise stated.

Table 1.—A comparison of codling moth control with different strengths of DDT and with other insecticides.

Row	Material Used (Per 100 Gallons)	Apples Examined	Per Cent Worms	Per Cent Stings	DDT[1] gr./lb.
1 & 8	3 lb. lead in 7 sprays plus nicotine & oil in 2, 3, 6–7 covers.	22,187	24.6	13.1	
2	3 lb. lead in first five sprays plus oil & nicotine in 2 & 3 covers. 1 lb. DDT and 3 ounces sodium lauryl sulphate in 6th and 7th covers.	11,968	17.3	6.5	.03
3	3 lb. lead in petal fall, 1.5 lb. DDT and 3 ounces sodium lauryl sulphate in six other sprays.	10,572	14.3	3.1	.06
4	3 lb. lead in petal fall, 1 lb. DDT and 3 ounces sodium lauryl sulphate in six other sprays.	12,626	24.2	3.9	.032
5	1 lb. DDT in petal fall. 1 lb. DDT, and 3 ounces sodium lauryl sulphate starting with 2nd cover, for 5 sprays.	12,694	24.1	4.6	.035
6	3 lb. lead in petal fall, 8 oz. DDT and 3 ounces sodium lauryl sulphate in six sprays.	9,663	41.0	5.1	.022
7	3 lb. lead in petal fall. 8 oz. DDT and 3 ounces sodium lauryl sulphate plus 1 lb. lead in six other sprays.	12,000	27.7	4.3	.021

[1] DDT analysis run by the Insecticide Division of the Bureau of Entomology and Plant Quarantine.

Row 1 was located on one side of the DDT block and separated from it by one buffer row with the standard spray. Row 8 was on the opposite side of the DDT plot and also separated from it by a buffer row. The last sprays on all rows were applied July 25. The materials used, the average percentage of worms, stings and clean fruit for all varieties and the residue of DDT, in grains per pound of fruit, on the Grimes Golden, are shown in table 1.

All trees in the orchard where the tests were run had a full crop of apples. Past experience with standard sprays has shown that the lighter the crop the greater the percentage of codling moth injury. This generalization appears questionable in light of the results obtained with DDT on Red Starking in which the number of

Table 2.—A comparison of insecticide treatments according to size of crops.

Row	Material Used	Variety	Apples	Per Cent Worms	Per Cent Stings
1 & 8	Lead in 7 sprays plus nicotine & oil in 2,3,6–7 covers.	Grimes	6287	26.3	14.2
		Stayman	3771	12.6	8.7
		Red Starking	2305	34.8	16.0
2	3 lb. lead in 1st five sprays plus oil & nicotine in 2 & 3 covers. 1 lb. DDT in 6 & 7 covers.	Grimes	6092	14.1	7.8
		Stayman	4176	13.5	4.5
		Red Starking	1700	28.2	11.4
3	3 lb. lead in petal fall, 1.5 lbs. DDT in other six sprays.	Grimes	4282	12.8	4.3
		Stayman	2415	14.4	1.8
		Red Starking	1875	15.9	4.4
4	3 lb. lead in petal fall, 1 lb. DDT in other six sprays.	Grimes	5138	18.6	4.7
		Stayman	4774	28.2	3.5
		Red Starking	2714	22.0	3.7
5	1 lb. DDT in petal fall (skipped first cover spray). 1 lb. DDT starting 2 cover for 5 sprays.	Grimes	4361	29.1	3.8
		Stayman	5629	18.4	3.8
		Red Starking	2704	30.7	6.9
6	3 lb. lead in petal fall. 0.5 lb. DDT in other six sprays.	Grimes	4219	42.8	6.6
		Stayman	3691	34.3	4.2
		Red Starking	1753	52.8	5.3
7	3 lb. lead in petal fall. 0.5 lb. DDT plus 1 lb. lead in other six sprays.	Grimes	4901	18.8	4.9
		Stayman	3996	23.1	4.5
		Red Starking	3183	43.7	3.3

apples per tree was only approximately half that on the other varieties; the percentage of injury was nearly the same when 1 pound or more of DDT was used. The number of apples per tree, percentage of worms, stings and clean fruit for each variety in each test are shown in table 2.

In all cases the Red Starking had approximately half as many apples as the other two varieties. An analysis of the percentage of clean fruit of each variety shown in table 2 indicates that when DDT was used at the rate of one pound or more per 100 gallons in six sprays the per centage of clean fruit remained approximately the same on all three varieties. In those rows where DDT was used at less than one pound in five sprays, or one pound in two sprays and in the check rows, the clean fruit on the Red Starking dropped to as much as 19 per cent less than the other two varieties.

DISCUSSION.—When DDT was used at one pound or more in five sprays codling moth injury was held to a minimum until after August 10. The other combinations varied in effectiveness in holding the first brood moths, with one-half pound DDT being the least effective. In all cases the greater part of the injury occurred after August 10. It appears reasonable that the infestation on all rows could have been greatly reduced by the addition of two applications of spray, one on August 10 and the last approximately August 25.

Any combinations in which DDT was used proved more effective in reducing stings than the standard spray, but failed to show the same efficiency in reducing worms.

No injury was observed to the trees from any of the combinations used. No injury was noticeable on the Grimes or Stayman at harvest, but the Red Starking showed a russeting that was believed to be heaviest on the row sprayed with 1.5 pounds of DDT.

About the first of August, a severe infestation of European red mite developed on all the rows sprayed with DDT. The remainder of the orchard received four applications of oil and no red mite infestation developed.

CONCLUSION.—From these tests it appears that DDT in all strengths and combinations used in these tests except the one-half pound dosage gave control of codling moth as good as, or better than, the standard sprays used as checks.

The data in table 2 indicate that where DDT is used at the strength of one pound or more per 100 gallons of spray the percentage of clean fruit will be approximately the same regardless of the size of the crop. This is not true in case of the standard schedules.—1-9-45.

SCIENTIFIC NOTES

DDT to Control *Glossonotus crataegi*[1]

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In western New York localized infestations of the quince treehopper, *Glossonotus crataegi* (Fitch), become sufficiently severe to cause weakening of branchlets and twigs. Although the fruit is not attacked directly, it becomes covered with excrement and blackened by mold growth. Efforts to control this insect have not been overly successful except for dormant oil sprays as reported by Harman (1938).

In 1944 DDT, 1 pound to 100 gallons, applied to quinces to control the oriental fruit moth caused the complete disappearance of treehopper nymphs from the trees. Two weeks later the same material gave a like result against the half grown nymphs. To verify and enlarge upon these observations a series of concentrations of DDT, formulated as a 25 per cent water dispersible powder, was applied on July 23 to the outside row of a heavily infested quince block. At this time 95 per cent of the insects were in the adult stage. Immediately after spraying, cloths were spread under one half of a tree in each treatment. One day later the fallen hoppers were collected for counting and some of the cloths returned for further collections. Counts were made also on the living hoppers in the trees 24 hours after treatment. The results are summarized in table 1.

Table 1.—Effect of DDT on the adult quince treehopper.

DDT in 100 Gallons	Dead Hoppers Collected from Cloths After Treatment			Hoppers on Treated Trees After 24 Hours
	1 day	10 days	20 days	
2 ounces	1666	—	—	48
4 ounces	1201	—	—	46
8 ounces	1359	—	—	28
12 ounces	2067	102	—	18
16 ounces	1618	142	20	12

The knockdown of treehoppers was complete with all concentrations. However, a large number were still alive on the cloths at the end of 24 hours under the trees treated with the two low dosages. It is possible that some may have returned to the trees although it is more likely that the hoppers present at the end of 24 hours represent a reinfestation from adjacent trees since they were found largely on that side. The differences in the extent of reinfestation and the kill obtained during the 10 and 20 day periods following treatment attest the residual effect of the heavier concentrations of DDT against this insect. From these results it would seem feasible for a grower to eliminate the quince tree hopper from isolated plantings early in the season. Where reinfestation by adults could occur, additional treatments should be effective.—2-17-45.

[1] Journal Paper No. 617. N. Y. State Agricultural Experiment Station, Geneva, N. Y.

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Toxicity of DDT to Fish

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While conducting experiments with 2,2 bis (p-chlorophenyl) 1,1,1 trichlorethane (DDT) as a possible mosquito larvicide, the writer has noted that this chemical is toxic to several species of fish.

Black Bass.—Preliminary tests in 1943 at the New Jersey State Fish Hatcheries, with a diluted kerosene emulsion, containing 0.1 per cent DDT proved fatal to black bass, *Micropterus salmoides* (*Lacepede*), within 3 days after application.

Catfish.—In August 1944 a shallow pond, about two acres in area, breeding *Anopheles quadrimaculatus* was sprayed with a diluted kerosene emulsion containing 0.2 per cent DDT. Two days after application many dead catfish were found on the surface. It may be of interest to report here that two water snakes and one turtle, living in the pond, were also dead.

Salt Water Minnows.—During the same month six salt marsh test holes (2.5 feet deep, 54 feet square) breeding mosquito larvae were treated with various concentrations of a water miscible solution of DDT in xylol. One of these test areas, receiving 1 part DDT to 4,000,000 parts of water, contained at the time of treatment some salt water minnows, *Fundulus hetoroclitus macrolepidatus*, Walbaum. Two days after application, five of the fish were found dead on the surface.

Recently Ellis *et al.* (1944)[2] reported that DDT is more toxic to frogs and goldfish than to the common laboratory mammals (rats, cats and rabbits).

TESTS ON GOLDFISH, *Carassius auratus.*—As a result of these casual field observations, it was deemed advisable to secure more definite and systematic information under laboratory conditions on the toxicity of DDT to fish. The common goldfish, *Carassius auratus*, was found convenient for laboratory experiments. The fish were obtained from a local fish hatchery establishment and were about six months old, averaging 1.5 gm. in weight and 5.7 cm. in length. During the summer of 1944 tests were conducted with various concentrations of DDT as (1) colloidal dispersions, (2) oil emulsions and (3) dusts. It was thought that these three phases may comprise most, if not all, forms in which DDT may be utilized in preparing mosquito larvicides.

COLLOIDAL DDT DISPERSIONS.—Since DDT is not soluble in water it was necessary to select a solvent by which it could be uniformly dispersed in water for the duration of the experiment. Preliminary tests have shown that ethyl alcohol, in which up to two per cent DDT can be dissolved at room temperature, proved efficient for this purpose. Glass jars of one gallon capacity, each containing five

[1] Journal Series paper of the New Jesrey Agricultural Experiment Station, Rutgers University, Department of Entomology.

[2] Ellis, M. M., Westfall, B. A. and M. D. Ellis, 1944. Toxicity of DDT to Goldfish and Frogs. Science 100(2604): 477.

fish in 2.5 liters of tap water were used. The fish were transferred to the jars several hours before treatment in order to acclimatize them to their new environments. Once a day the fish were fed ordinary fish food. Fresh oxygen was incorporated in the water by bubbling through air in each jar for about three minutes every day. The concentrations of DDT ranged from 1 to 100,000 to 1 to 20,000,000. The fish were kept under observation for six days. After this period the water in the jars started to stagnate and the tests were discontinued. Two series of experiments, identical in every respect, were run, giving a total of 10 fish per each concentration of DDT.

The average results of the two series, presented in table 1, bring out the following information. In concentrations of 1 to 500,000 or lower all fish died within 24 hours. Concentrations of 1 to 1,000,000 and up to 1 to 5,000,000 gave 100 per cent kill within 2 days. In 1 to 10,000,000 only 40 per cent of the fish were dead at the end of 6 days. None were dead in 1 to 20,000,000 and in the checks during the period of testing.

Table 1.—Tests with alcoholic solutions of DDT on goldfish.

DDT Dilutions	No. of Fish per Test	Per Cent Dead After 1 Day	2 Days	6 Days
1–20,000,000	10	0	0	0
10,000,000	10	0	0	40
7,500,000	10	20	30	80
5,000,000	10	60	100	
2,500,000	10	90	100	
2,000,000	10	90	100	
1,000,000	10	90	100	
500,000	10	100		
250,000	10	100		
100,000	10	100		
None	10	0	0	0

DDT Emulsions.—A standard grade of water-white kerosene containing three per cent DDT in solution was emulsified with sodium lauryl sulfate and designated for experimental purposes as "Mosquito Larvicide 50-D." The concentrated emulsion contained approximately two parts kerosene and one part water with 2 per cent DDT, and 0.5 per cent emulsifier. For testing it was diluted with 10 parts of water and applied by pipette in quantities equivalent to 25, 50 and 100 gallons per acre. The tests were carried out in glass jars, employing the same technique as described above. In this case the emulsion deposited a thin film of emulsified oil, holding the DDT on the surface of the water. The results, presented in table 2, show a high rate of toxicity within six days after application, ranging from 60 per cent in the 25 gallon to 80 per cent in the 100 gallon applications respectively.

DDT Dust.—The tests were carried out in small aquaria filled to a depth of five inches with six liters of tap water, giving a water surface area of 0.58 square feet and a volume of 0.24 cubic feet. Each aquarium contained six goldfish. Dust mixtures of 1 per cent and 0.1 per cent DDT, prepared from a commercial sample of 20 per cent DDT micronized with pyrophyllite, by mixing in soapstone as a diluent, were used. The concentrations ranged from

Table 2.—Tests with DDT emulsion (50-D) on goldfish.

Gallons of 1–10 Emulsion per Acre	DDT Pounds Per Acre	DDT Dilutions	No. of Fish per Test	Per Cent Dead After 3 Days	6 Days
25	0.42	1–2,500,000	10	30	60
50	0.85	1,125,000	10	40	60
100	1.7	562,500	10	60	80
Check 100 (kerosene emulsion)	None	None	5	0	0

0.1 pound to 2 pounds of pure DDT per acre. As in the previous experiments, the tests were continued for 6 days, aerating and feeding daily. The dust, uniformly distributed on the surface, continued to float during the first day after application but gradually sank to the bottom. The fish in all treated aquaria exhibited great excitement during the first two days, continuously darting back and forth in all directions.

The data presented in table 3 indicate that DDT in dust form is less toxic to fish than in colloidal dispersion. The kill after six days was only 33 per cent for concentrations ranging from 0.1 to 1 pound per acre (from 1 to 10,000,000 to 1 to 1,000,000) and an average of 83 per cent where 2 pounds per acre were used.

At the end of the six days' period 12 of the surviving fish from treated aquaria 1, 2, 3 and 4, were thoroughly washed, transferred to fresh tap water in two aquaria, six fish in each, fed and aerated daily, and kept for further observations. The 12 fish from the two check aquaria were similarly treated. After six days five fish from the previously DDT-treated batch were dead, whereas all fish in the check batch were alive. Apparently DDT continues to exert a deleterious effect on fish even after the treatment has been discontinued.

Table 3.—Tests with DDT dust on goldfish.

Aquarium No.	DDT Pounds per Acre	DDT Dilutions	No. of Fish per Test	Per Cent Dead After 3 Days	6 Days	
1	0.1	1–10,000,000	6	0	33	
2	.2	5,000,000	6	17	33	
3	.5	2,000,000	6	17	33	
4	1.0	1,000,000	6	17	33	
5	2.0	500,000	6	33	100	83
6	2.0	500,000	6	17	66	
7	Check 2.5 gm. Soapstone	None	6	0	0	
8	Check Water only	None	6	0	0	

Comparing the results in the three tables, it appears that DDT is most toxic to goldfish when in colloidal dispersion, less toxic in surface application in form of oil emulsion; and least toxic when applied as dust. In each case, however, the toxicity is sufficiently high to caution against unrestricted use of DDT on mosquito breeding waters where fish, worth preserving, prevail.

Summary and Conclusions.—Observations in the course of field experiments with mosquito larvicides containing DDT have indicated that this chemical is toxic to black bass, catfish and salt water minnows. Laboratory experiments with various concentrations of DDT applied as (1) colloidal dispersion, (2) oil emulsion and (3) dust have shown high toxicity to goldfish.—1-9-45.

DDT to Control the Cotton Leafworm

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In cage tests conducted at Waco, Texas, in 1943 (Ivy 1944a), DDT was found to be less effective against the cotton leafworm, *Alabama argillacea* (Hbn.), than against some other insects. Further tests with this material against the cotton leafworm, including several field experiments in 1944, confirm these results.

Two series of cage tests were conducted in which field-growing cotton plants were dusted in a dusting chamber (Ivy 1944b) with 2 per cent DDT-pyrophyllite, as compared with 1 1 calcium arsenate-sulfur or calcium arsenate. In both series the larvae were placed on the plants before the dust was applied, to afford an opportunity for it to act both as a contact and stomach poison. As indicated in table 1, the DDT was less effective than the calcium arsenate, either alone or mixed with sulfur.

Table 1.—Field cage tests with DDT against third-instar cotton leafworms, Waco, Tex.

Material	Rate of Application per Acre	Cages	Larvae	Net Kill in 5 Days[1]
	Pounds	*Number*	*Number*	*Per Cent*
Series 1:				
2 per cent DDT-pyrophyllite	32	18	159	28
1:1 calcium arsenate-sulfur	16	18	163	89
Untreated check cages	—	18	157	—
Series 2:				
2 per cent DDT-pyrophyllite	32	12	100	36
Calcium arsenate	8	12	116	97
Untreated check cages	—	12	122	—

[1] Calculated by Abbott's formula. Mortality in the check cages was 10 per cent in series 1 and 1 per cent in series 2.

In laboratory tests using technique reported for the bollworm, *Heliothis armigera* (Hbn.), (Ivy 1944a), it was found that the median lethal dosage of DDT in a water suspension applied to the dorsa of 170 fifth-instar cotton leafworms was 61.5 mg. per gram of body weight, or 206 times that found for the bollworm (0.299 mg.).

In a field-plot experiment at Waco 24 tenth-acre plots arranged in a randomized block were used to compare calcium arsenate with 1, 2, 4, and 8 per cent of DDT in pyrophyllite, when applied at the rate of 16 pounds per acre-application. Dust applications were made on August 2, 7, and 9. The August 7 application was partially washed off by rain. Calcium arsenate gave ample control of the leafworm, but following the third application of DDT it was necessary to dust the plots with an arsenical to prevent defoliation.

In another field experiment, at Bryan, Tex., DDT was compared with calcium arsenate in dust applications by ground machines and with cryolite applications by airplane. Four per cent of DDT in pyrophyllite at the rate of 16 pounds per acre-application was used. The plots ranged in size from 1.5 to 9.3 acres. Two applications of each material had been made for control of the bollworm, when leafworms appeared during the first week in August. The regular schedule of dusting at intervals of 5 to 7 days was continued for two more applications. Within 6 days after the fourth application it became necessary to dust the DDT plots with an arsenical to prevent complete defoliation by the leafworm. In the airplane dusting experiment considerable ragging had already been done in the DDT plot before the arsenical was applied, whereas the adjoining plot dusted with cryolite did not show any ragging. A distinct line of demarcation between the plots dusted with DDT and those dusted with cryolite could be observed from a considerable distance.

A small-plot experiment was conducted on August-planted cotton at Waco to compare the residual effect of DDT when applied as a spray and as a dust. Twelve plants were dusted 6 times with 4 per cent of DDT in pyrophyllite at the rate of 16 pounds per acre-application at 5-day intervals between September 11 and October 5. During the same period 12 plants on an adjoining row were sprayed 6 times with the same amount of DDT (0.64 lb.) per acre-application. The spray was a suspension of 21 pounds of 10 per cent DDT in pyrophyllite in 100 gallons of water applied at the rate of 30 gallons per acre. Only 1.02 inches of rainfall occurred during this 25-day period. A heavy infestation of leafworms developed in this field beginning about September 26, or after four applications of insecticide. The numbers of larvae averaged 13.8 per plant on the dusted plants and 9.2 on the sprayed plants, representing reductions of 61.6 and 74.4 per cent below the numbers on untreated check plants in an adjacent row. Although the DDT spray caused a greater reduction than the dust, neither treatment prevented the almost complete defoliation of the plants by surviving larvae and larvae migrating from other plants. A seventh application of both dust and spray was made on October 10, but both treated and check plants were so defoliated by October 14 that further counts of leafworm larvae could not be made.

SUMMARY.—In field-cage tests with DDT against the cotton leafworm, *Alabama argillacea* (Hbn.), a 2 per cent DDT-pyrophyllite dust was only about one-third as effective as calcium arsenate or 1:1 calcium arsenate-sulfur dust. The median lethal dose of DDT in a water suspension applied to the dorsum was 61.5 mg. per gram of body weight, or 206 times greater than for larvae of the bollworm, *Heliothis armigera* (Hbn.). In field-plot experiments with dusts containing 1, 2, 4, and 8 per cent of DDT in pyrophyllite, applied at the rate of 16 pounds per acre-application, defoliation occurred after the third application. In other experiments 4 per cent DDT-pyrophyllite dust applied at the same rate by ground machines and by airplane failed to control leafworms. Tests to compare the residual effect of sprays and dusts containing DDT showed reductions of 74.4 and 61.6 per cent, respectively, after six applications at 0.64 pound of DDT per acre, but neither treatment prevented almost complete defoliation of the plants.—3-6-45.

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[1] In cooperation with the Texas Agricultural Experiment Station.

DDT to Control *Psallus ancorifer* in Onions

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A small plant bug, *Psallus ancorifer* (*Rieber*), is a serious pest of onions grown for seed in Oregon. It works in the heads at the time the onions are in bloom, causing the bloom to blight. The margins of the field are more heavily damaged: therefore, small plantings suffer the heaviest loss. Losses from this insect vary from 5% to 50%, depending on the size and location of the field.

Gesarol A-3 dust was applied to a plot of seed onions heavily infested with this insect. An examination before the application was made revealed 25 to 75 bugs per head, sufficient infestation to cause total loss of the seed crop. The dust was applied with a bellows type hand duster under very windy conditions and apparently a poor coverage was obtained. Nevertheless, excellent control was obtained. A check made 48 hours after dusting showed the dusted block to be entirely free of live bugs. A number of dead bugs were found down deep in the onion blossoms. A full seed crop was obtained from the dusted plot. The undusted portion of the field suffered a 50% loss from the action of this insect.—2-19-45.

Residual Action of DDT Aerosols Against Houseflies

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The effectiveness of DDT spraysasa residual contact insecticide has been reported by Lindquist *et al.* (1944) and Madden *et al.* (1944). It appeared likely that residues from DDT aerosols would also be toxic to insects. In March 1943 a few preliminary tests at Orlando, Fla., using 20 per cent of DDT in methyl chloride in rooms heavily infested with bedbugs gave highly effective results. The aerosol was directed over and under the bedsprings and mattresses and on walls and baseboards. In another series of tests, to be described herein, aerosols containing DDT in *Freon-12* were released in small rooms and in boxes in connection with studies of residual toxicity to houseflies.

In the room tests two aerosols containing DDT and, for comparison, the pyrethrum-sesame oil aerosol, were released from time to time in 700-cubic-foot rooms. For each treatment 3 grams of aerosol was discharged into the center of the room, no attempt being made to discharge it against the walls or ceiling. After various intervals from 80 to 100 houseflies were exposed in each room for 24 hours, and at the end of this time mortality records were taken. The results are given in table 1.

The kill was 97 per cent or better up to 10 days after only one treatment with the 5 per cent DDT aerosol. The pyrethrum-sesame oil aerosol, applied in the same way, gave kills of 17 per cent or less. The 2.5 per cent DDT aerosol showed kills roughly half that of the 5 per cent DDT formula.

The amount of DDT discharged in these aerosols is exceedingly small, averaging approximately 0.35 mg. per square foot if it were equally distributed over the walls, ceiling, and floor. Actually such an even distribution does not occur, since the major portion settles on the floor, and this is one of the weaknesses of this method of applying a DDT residue. Experiments have demonstrated that small particles do not stick well to vertical or overhead surfaces, but drop to the floor in two to three hours. On the other hand, wet sprays (large particle size) have been found to be practical in obtaining a DDT residue on such surfaces without excessive loss of spray into the air. The data indicate, however, that an effective residue against flies can be built up by continued use of DDT aerosols.

In the box tests (Table 2) for each treatment 1 gram of aerosol was released in 100-cubic-foot boxes. The results were similar to those obtained in the room tests. In this series a new formula—DDT, 3 per cent, plus cyclohexanone, 5 per cent, plus lube oil, 5 per cent, plus pyrethrins, 0.2 per cent, in *Freon-12*—was included. Lindquist *et al.* (1944) demonstrated the value of adding motor oil to DDT aerosols for use against flying insects. This new formula gave the best immediate results and after six applications was equal to the 5 per cent DDT.

[1] This work was conducted under a transfer of funds, by the Committee on Medical Research, from the Office of Scientific Research and Development to the Bureau of Entomology and Plant Quarantine.

Table 1.—Per cent kill of houseflies 24 hours after introduction into rooms previously treated with *Freon* aerosols containing DDT and pyrethrum.

Rooms Treated	Flies Released	Cyclohexanone 10% +Pyrethrins 0.2% +DDT 5%	Cyclohexanone 10% +Pyrethrins 0.2% +DDT 2.5%	Pyrethrins 0.4% +Sesame Oil 8%	No Treatment
Nov. 29	Nov. 30	97	48	2	9
	Dec. 4	99	93	17	17
	6	99	20	6	—
	10	99	60	9	9
	Jan. 4	37	14	13	2
Jan. 5	6	99	48[1]	4[2]	4
8[3]	10	78	91	3	4
13	14	98	48	1	1
17, 18, 19	20	100	99	4	6
	26	97	100	1	4

[1] Sprayed with following formula: DDT 3%+cyclohexanone 5%+motor oil 5%+pyrethrins 0.4%.
[2] Spraying discontinued and this room used as a check.
[3] Only room 4 treated on this date.

Table 2.—Per cent mortality of houseflies 24 hours after introduction into boxes previously treated with *Freon* aerosols containing DDT and pyrethrum.

Boxes Treated	Flies Released in Boxes	Box 1 DDT 3%+Cyclohexanone 5% +Lube Oil 5% +Pyrethrins 0.2%	Box 2 DDT 5%+Cyclohexanone 10% +Pyrethrins 0.2%	Box 3 Pyrethrins 0.4% +Sesame Oil 8%	Box 4 No Treatment
Jan. 3	Jan. 4	80	47	6	0
7	8	100	85	2	0
	12	51	34	2	2
14	15	94	97	5	0
20, 21, 22	24	92	93	37	5
	28	95	94	18	6

These tests indicate that DDT aerosols will leave a residue that is toxic to houseflies introduced after the aerosol has settled. Although the purpose of DDT aerosols is primarily to kill flying insects quickly by contact, the continued use of this insecticide in aerosol form will in time leave a deposit that will be a valuable adjunct in control. Where it is desired to obtain control by taking advantage of the persistent residual action of DDT, the residue should be obtained by the application of wet sprays. —8-21-44.

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DDT for the Control of Grape Leafhoppers[1]

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In a study of substitutes for nicotine sulphate for the control of grape leafhoppers, *Erythroneura* spp., field tests, comparing the effectiveness of various insecticides, were conducted in the Erie Grape Belt, in 1944. Although a number of materials were included in the tests, only sprays of DDT, nicotine sulphate and *Lethane B-72* are included in this report.

Methods and Materials.—Tests were conducted in three commercial vineyards in the vicinity of North East. The vineyards were located on sandy and gravely soils, and were planted to the variety Concord. The vines were trained to the umbrella system. The sprays were applied with a power sprayer and a covered, inverted U-shaped boom carrying five nozzles on each side of the row. From 150 to 200 gallons of materials were used per acre. The plots were 6 to 8 rows wide. The rows were 9 feet apart and ranged from 100 to 120 vines per row Since there are approximately 600 vines to the acre when planted 8 feet by 9 feet, each plot was approximately one acre in size.

Population studies, expressed as the number of leafhoppers per 10 leaves, were determined by the method given by Hartzel & Horsfall (1944). The leaves were collected from 10 vines in the center rows of each plot. Only leaves were selected that appeared to be representative of the infestation in a given vineyard. An aliquot fraction of the sample was used to determine the infestation of a plot unless the total catch was less than 100 leafhoppers.

The materials used in the experiments were as follows: Nicotine sulphate, 40 per cent nicotine, *Black Leaf 40; Gesarol AK-20*, 20 per cent dichloro diphenyl trichloroethane (DDT); *Lethane B-72*, 13.5 per cent Beta Beta dithiocyano diethyl ether; *Sunoco Oil*, a miscible oil, and *Orthol D-soluble*, a miscible oil.

Field Experiments.—In early June, before Concord grapes bloomed, a portion of a vineyard was sprayed with *Gesarol AK-20* (DDT). Later in the season the entire vineyard was sprayed by the grower with nicotine sulphate. During the latter part of July it was observed that there was a decided reduction in the leafhopper population in that portion of the vineyard that was sprayed with DDT. A summary of the results is given in table 1 (Vineyard A). By early September there were more than 22 times as many leafhoppers on the plots sprayed with nicotine sulphate as on the plots sprayed with DDT and nicotine sulphate.

In order to determine the value of insecticides in the post bloom and 10 day sprays for the control of grape leafhoppers, sprays were applied to portions of a vineyard the latter part of June and the first part of July. A summary of the results are shown in table 1 (Vineyard B). In table 1, it may be seen that two sprays of either nicotine sulphate or *Lethane B-72* greatly reduced the leafhopper population. However, neither nicotine sulphate nor *Lethane B-72* prevented a build-up of the leafhoppers, and by the first part of September there were nine times as many leafhoppers on the plots sprayed with nicotine sulphate and 20 times as many leafhoppers on the plots sprayed with *Lethane B-72* as on the plots sprayed with DDT.

To secure information on the value of mid-season sprays for the control of grape leafhoppers, sprays were applied in mid-July and early August to parts

[1] Authorized for publication on December 28, 1944, as paper No. 1264 in the Journal Series of the Pennsylvania Agricultural Experiment Station.

Table 1.—Summary of results of experiments for grape leafhoppers.

MATERIAL AND AMOUNT PER 100 GALLONS		APPLICATIONS	LEAFHOPPERS PER 10 LEAVES				
			July 5	July 19	July 24	Aug. 22	Sept. 5
		Vineyard A					
Gesarol AK-20,	2.4 lbs.[1]	June 8	—	—	1	—	67
Nicotine sulphate (*Black Leaf 40*),[2]	¾ pt.	June 23	—	—	587	—	1504
		July 5					
		Vineyard B					
Gesarol AK-20,	1.6 lbs.[2]	June 23	2	3	—	—	98
Nicotine sulphate (*Black Leaf 40*),[2]	½ pt.	June 23	4	224	—	—	898
		July 3					
Lethane B-72,	1.9 lbs.[2]	June 23	6	655	—	—	1968
		July 3					
Lethane B-72,	2.8 lbs.[2]	June 23	3	540	—	—	1872
		July 3					
Lethane B-72,	3.8 lbs.[2]	June 23	2	464	—	—	1744
		July 3					
Checks[3]		—	870	—	—	—	—
		Vineyard C[4]					
Gesarol AK-20,	3 lbs.	July 18	—	—	3	11	14
Orthol D-soluble,	2 qts.						
(*Black Leaf 40*),	1 pt.	July 18	—	—	20	287	920
Orthol D-soluble,	2 qts.						
Lethane B-72,	3 lbs.	July 18	—	—	71	396	888
Orthol D-soluble,	2 qts.						
Gesarol AK-20,	2 lbs.	Aug. 11	—	—	—	25	5
Sunoco oil,	3 qts.						
Checks		—	—	—	383	957	1296

[1] Applied with *Sunoco oil* 3 qts., and bordeaux mixture 4–4–100. Received on June 23 and July 5 lead arsenate 3 lbs., *Sunoco oil* 3 qts., nicotine sulphate 0.75 pt. and bordeaux mixture 4–4–100.
[2] Applied with lead arsenate 3 lbs., *Sunoco oil* 3 qts., and bordeaux mixture 4–4–100.
[3] Received nicotine sulphate 0.5 pt. to 100 gallons July 6. No later counts made.
[4] Previous to treatment, vineyard C was sprayed by the grower (post bloom and 10 day sprays) with nicotine sulphate 0.5 pt., lead arsenate 3 lbs., *Sunoco oil* 3 qts. and bordeaux mixture 4–4–100.

of a vineyard that had previously been sprayed by the grower with nicotine sulphate. A list of the materials and the results of the tests are shown in table 1 (Vineyard C). Sprays of DDT gave a greater reduction in the leafhopper population than sprays of nicotine sulphate and *Lethane B-72*. By early September there were many times as many leafhoppers on the plots sprayed with nicotine sulphate and *Lethane B-72* as on the plots sprayed with DDT.

DISCUSSION.—The data in table 1 indicate that one spray of *Gesarol AK-20* (DDT) will give satisfactory control of grape leafhoppers. Apparently, DDT is toxic to the adults as well as the nymphs, as one spray of DDT applied before Concord grapes bloomed gave a high degree of control. Early season sprays of DDT appear to be more satisfactory than mid-season sprays in that the leafhopper damage is reduced to a minimum. Population studies, made soon after the sprays were applied, indicate that nicotine sulphate and *Lethane B-72* are quite toxic to grape leafhoppers. However, nicotine sulphate and *Lethane B-72* did not prevent a build-up of leafhoppers and by early September considerable damage was evident on the foliage. Observations indicate that the residual effect of DDT sprays lasts for several weeks. However, by early September some leafhoppers were present on the outside rows of the DDT plots and some injury was evident on the foliage. Although no injury to the fruit or foliage of Concord grape was observed where *Gesarol AK-20* (DDT) was used, Siegler (1944) found that one spray of DDT, applied at the rate of 4 pounds to 100 gallons, severely injured the foliage of Concord grape. No injury was observed where *Lethane B-72* sprays were used. From one season's work it appears that sprays of DDT offer a great deal of promise as a control for grape leafhoppers.

SUMMARY.—Under field conditions one application of *Gesarol AK-20* (DDT) spray gave satisfactory control of grape leafhoppers. Sprays of DDT appear to be toxic to the adults as well as the nymphs, and the residual effect lasts for several weeks. Early season sprays appear to be more satisfactory than later sprays. Population counts, made soon after the sprays were applied, showed that nicotine sulphate and *Lethane B-72* were quite toxic to the leafhoppers. No injury to the fruit or foliage of Concord grape was observed where *Gesarol AK-20* and *Lethane B-72* sprays were used.—1-11-45.

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DDT in the Codling Moth Program for Western New York[1]

S. W. HARMAN, *New York State Agricultural Experiment Station, Geneva*

This paper presents the results of orchard tests in codling moth control with DDT during the past season. The materials used included:

Geigy Company's *Gesarol AK20*, a dry 20 per cent DDT concentrate without spreader, used at the rate of 4 pounds in 100 gallons, or in other words 0.8 pound of actual DDT in 100 gallons.

The Rohm & Haas product, *B1956*, was employed as a spreading and wetting agent, 2.5 ounces in 100 gallons.

Du Pont's *Fermate*, 1.5 pounds in 100 gallons, was combined with the DDT in the first two cover sprays for protection against apple scab.

One quart of Socony Vacuum Oil No. 875 (*Prorex oil C*) was added to 4 pounds of the *AK20* mixture to make the DDT-oil spray.

Gesarol A3 dust, containing 3 per cent DDT in an inert carrier, was used at the rate of from 2 to 3 pounds per application on trees bearing from 10 to 15 bushels of fruit.

Acid lead arsenate, 3 pounds in 100 gallons with 3 pounds of hydrated lime and 0.5 pound of soybean flour, was the standard spray used for comparison. Micronized sulfur was added in the two first cover sprays for scab protection.

The tests were made in a young McIntosh orchard maintained specially for testing insecticides. Each row consisted of 20 trees and each plat included at least one row. Several thousand apples were counted on each plat for record. Applications were made with a *Friend* orchard sprayer equipped with a 20-gallon pump, a 300-gallon tank and a *Friend Pecan* gun using 400 pounds pressure at the pump. Where the complete summer schedule consisted of five cover sprays the first three were applied on June 9, 22 and July 1 for the first brood worms and two later applications on August 1 and 14 were for second brood control.

Approximately 10 per cent of the trees scattered throughout the orchard were left unsprayed following the petal fall applications for the purpose of providing a continuous supply of codling moth during the growing season. The infestation was so general throughout this planting that it was very unusual for any unprotected fruit to come through the season free of blemish.

Codling moth control on the several plats is given in table 1.

A standard lead arsenate spray, plat 1, containing 3 pounds of the arsenical in 100 gallons, and a DDT spray, plat 2, using 0.8 pound of actual DDT in 100 gallons provided almost identical control of both stings and worms. On plat 3 double the interval was left between applications of DDT and the control was considerably reduced with the worm count jumping from 5 to 40 per cent. This was a very striking condition indicating that the protective value of DDT spray residue fell off rapidly following the 10-day to 2-week interval between applications.

When oil was added in small amounts, plat 4, the control improved as compared with a similar schedule without the oil, plat 2. Omitting the final cover spray, plat 5, or in other words using one DDT-oil spray for the second brood worms, the figures indicate reduced protection.

A 3 per cent DDT dust, Plat 7, applied on June 9, 22, 30, July 10, August 1 and 13 gave some protection but not nearly as effective as the DDT spray. These dust applications were made with an orchard duster during the heat of the day and on dry fruit and foliage which is not conducive to best control. If applications were made in the late evening, thereby taking advantage of quiet and more humid conditions, and possibly incorporating a small amount of oil in the dust, it is reasonable to believe that better protection would have been afforded with the dust program.

There was little or no visible spray residue on the fruit sprayed with DDT. On the contrary the fruit on the lead arsenate plat required cleaning.

Aside from some browning to portions of the foliage in the fall, there were no injurious results observed from any of the DDT sprays or dusts. It was thought that in the bronzed areas the chlorophyll might have been destroyed by the DDT, but analyses[2] of the leaves indicated no destruction of chlorophyll. Another possible explanation was that the red mite may have been causing the bronzing of the foliage but, generally speaking, this pest is of minor importance in most western New York apple orchards and in this particular orchard last year the mite population was very low. To check the possibility of mite injury careful and repeated counts revealed a very small population of mites, too few to cause injury, and no appreciable difference in numbers as compared with those on foliage of trees that had not received DDT. No counts exceeded an average of more than one mite per leaf and in most instances it was considerably less than this figure.

While making observations on the presence of red mites, counts were also made on the winged migrant aphids that were returning to the apple foliage. The aphids were just as abundant on the DDT sprayed foliage as they were on the lead arsenate plats. These aphids reproduced on the DDT plats apparently unaffected by the residue from the full schedule of sprays applied during the summer.

Table 1.—Codling Moth Control, 1944.

Materials[1]	Cover Sprays	Apples Counted	Stings (per 100 apples)	Worm Holes (per 100 apples)
Sprays				
1, lead arsenate 3 lbs.	1, 2, 3, 4, 5	7351	14.8	5.3
2, *Gesarol AK20* 4 lbs.	1, 2, 3, 4, 5	5554	10.9	4.7
3, *Gesarol AK20* 4 lbs.	1, –, 3, 4, –	4018	29.0	40.5
4, *Gesarol AK20* 4 lbs. +oil 1 qt.	1, 2,			
	Gesarol AK20 4 lbs. 3, 4, 5	3592	8.5	2.6
5, *Gesarol AK20* 4 lbs.	1, 2	4585	13.1	9.7
	Gesarol AK20 4 lbs. 3, 4, – +oil 1 qt.			
6, Checks		3350	22.1	137.1
Dust				
7, *Gesarol A3*	1, 2, 3, 4, 5, 6	1208	14.5	18.6

[1] Amounts used in 100 gallons.

On the contrary apple trees that were fall sprayed with DDT on October 7 showed comparatively few winged migrant aphids during the three weeks immediately following the applications and in no instance where aphids were found were any young able to establish themselves. It would appear from these observations that DDT spray residue either weathers off after a few weeks' time or perhaps

[1] Journal Paper No. 615, New York State Agricultural Experiment Station, Geneva, N. Y.

[2] Analyses made by F. Z. Hartzell.

breaks down into some compound that is much less toxic to apple aphids and codling moth.

CONCLUSION.—Judging from the results of one year's orchard tests it appears that DDT may prove a good substitute for lead arsenate under western New York conditions. Used at the rate of 0.8 pound in 100 gallons control equal to that with 3 pounds of lead arsenate could be expected. Larger amounts may prove more effective than the arsenical. There was no apparent injury either to the trees or fruit following applications of DDT although a distinct bronzing was noticeable on the foliage late in the fall. There was little or no visible residue at harvest following 5 cover sprays and the cost at present is little more than that of lead arsenate. Undoubtedly DDT will not be used extensively on fruit until after a tolerance has been established. However, contrary to some of the early opinions, DDT residue appears to either weather off or possibly break down into a less toxic form following application. This thought is prompted by reason of the experience that DDT residue was non-toxic to the codling moth and apple aphids following the lapse of a few weeks after application.—12-14-44.

DDT and *Ryanex* to Control Oriental Fruit Moth on Quince[1]

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The quince harvest in western New York is between 30 and 40 thousand bushels annually. In recent years the severe damage done to this profitable crop by the oriental fruit moth, *Grapholitha molesta* Busck., has threatened the continued existence of the industry. Biological control has not been effective. Daniel & Cox (1936) report the results of several years work in which numerous materials and schedules were tested under orchard conditions. Lead arsenate or combinations of lead arsenate, nicotine and oil similar to those used against the codling moth gave 90 to 98 per cent control. However, in the areas of heavy fruit moth infestation these materials have failed to protect the crop adequately.

Driggers (1944) and Carmen (1944) found DDT effective against the oriental fruit moth. This paper reports the results obtained in field tests to determine the comparative efficiencies of DDT, *Ryanex* and standard materials and schedules for the control of this insect on quinces.

The tests were conducted in a large, heavily infested, mature orchard in Orleans County. The grower-sprayed trees received four applications of lead arsenate, 3 pounds to 100 gallons followed by six sprays containing 0.75 per cent summer oil in addition to the lead. These materials were applied at approximately 10-day intervals between June 3 and September 5. Counts made in this block on October 18 showed an average of 133.2 worms per 100 fruits and but 47 per cent clean fruit.

In the test block all spraying was done from the ground, using standard orchard equipment. For the control of leaf spot, fruit spot and brown rot sulfur was applied in a preblossom spray; bordeaux mixture 3-8-100 was added to the other materials in the applications of June 3 and 13, July 24 and September 1. Except for two DDT schedules 10 days elapsed between sprays until lower temperatures in September allowed the final spray to be delayed until September 20, 9 extra days. Details of the tests and the results obtained from counts made on October 17 are summarized in Table 1.

Table 1.—Oriental fruit moth control in quinces.

No.	Treatment: Materials in 100 gallons		Applications	Total Fruits	Per Cent Clean	Worms per 100 Fruits
1	Lead arsenate	3 lbs.				
	Prorex C oil	2 qts.	11	1164	85	21.6
	B1956[1]	4 ozs.				
2	Lead arsenate	3 lbs.	3			
	B1956	4 ozs.	followed			
			by	1536	78	40.2
	Black Leaf 155	2 lbs.				
	Prorex C oil	2 qts.	8			
	Blood albumen[2]	4 ozs.				
3	Lead arsenate	3 lbs.	3			
	B1956	4 ozs.	followed			
			by	1383	74	41.4
	Black Leaf 40	1 pt.				
	Prorex C oil	2 qts.	8			
	Blood albumen	4 ozs.				
4	Lead arsenate	3 lbs.	3			
	B1956	4 ozs.	followed			
			by	1125	91	12.7
	Ryanex[3]	6 lbs.				
	B1956	4 ozs.	8			
5	DDT (actual)[4]	1 lb.	11	1113	99.5	0.4
6	DDT (same)	1 lb.	7	1192	98	2.4
7	DDT (same)	1 lb.	4	1080	79	30.2
8	No treatment	—	—	682	10	367.0

[1] From lot furnished by Rohm and Haas Co. in 1941.
[2] 3 ounces *B1956* substituted when bordeaux mixture was used.
[3] Furnished by Merck and Co., Inc.
[4] Furnished by E. I. du Pont de Nemours and Co.

Under these conditions the standard programs (Treatments 1, 2 and 3) failed to give better than 85 per cent clean fruit whereas identical programs in a moderately infested orchard produced better than 95 per cent of a light crop entirely free of injury.

It is apparent that *Ryanex* (Treatment 4) is toxic to the oriental fruit moth. No injurious effects were observed to either the plant or operators referable to the use of this new plant product. The results obtained in this preliminary test seem to warrant further experimentation.

The degree of control provided by DDT (Treatments 5, 6 and 7) even with reduced schedules, was striking. In treatment 6 all applications except the first two were separated by 20 days. The trees included in treatment 7 were sprayed on June 3, July 3, August 3 and September 1 only. It seems evident that a longer residual effect against the oriental fruit moth was obtained on quinces than has been recorded in the case of the codling moth on apples. This may be due to the dense pubescence covering the surface of the fruit throughout the season since the DDT suspension spread readily over the fruit and thoroughly soaked the hairy coating. The material used was formulated to contain 25 per

[1] Journal Paper No. 618, New York State Agricultural Experiment Station, Geneva, N. Y.

cent DDT mixed with an inert filler and suitable wetting agent.

Carmen (1944) and others find DDT residues toxic to the adult of the oriental fruit moth. Field observations indicate that this toxicity does not prevent oviposition upon sprayed surfaces. Of the quinces examined on trees sprayed six times with DDT 49 per cent were found to have developing eggs on the exposed surfaces of the sepals, a favored spot for oviposition.

No apparent injury to fruit or foliage resulted from the use of this formulation of DDT. However, there was a marked physiological effect best described at present as a possible stimulation of vegetative growth or a retardation of the ripening or maturing processes. At harvest, fruits from the DDT treatments were still green in color and quite pubescent as compared to the uniform yellow coloration and nearly glabrous condition of those treated otherwise. That this difference was associated with the use of DDT was attested by the obvious relationship observed between the degree of immaturity or hair retention and the number of applications of DDT. Whether any deleterious effect upon the tree will result from continued use of this chemical is at present problematical.

Samples of fruit from the DDT treatments and untreated trees were analyzed for residues of DDT by a modification of the Winter method for the determination of the halogen content of organic compounds as described by Hall *et al.* (1944). The results of these analyses are presented in table 2.

Table 2.—DDT residues on quinces at harvest on October 17[1]

Number of Applications	Inclusive Dates	DDT Residues	
		Parts per million	Grains per pound
11	June 3–September 20	12.5	0.087
7	June 3–September 20	6.7	0.047
4	June 3–September 1	4.0	0.028
1	June 23 only	1.6	0.011
none	—	0.7	0.005

[1] These analyses were made by Dr. Leland B. Norton of the N.Y.S. Agr. Expt. Sta. at Geneva.

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Experiments with DDT on Leaf-Cutting Ants in Ecuador

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Preliminary experiments conducted during July, 1944 in El Salvador indicated that the 10 per cent DDT-Pyrophyllite dust had some repellent effect upon the leaf-cutting ant *Atta cephalotes* (L.) when this material was applied to the entrances of their underground runways. Examination of these tunnels several days following the application revealed that the ants had ceased to use the tunnels. There were no indications that DDT had produced any toxic effects on the ants that might have come in contact with it while entering or departing from the nest.

At Pichilingue, Ecuador, five large *Atta* nests occupying on the average approximately 70 square meters (83.7 sq. yds.) of soil surface and located in a recently felled forest area were treated with the DDt mixture on October 2, 1944. In 3 nests an average of 24 ounces of the mixture was applied per colony in the principal openings of each nest by means of a cyanogas foot-pump. Two other nests were treated by broadcasting the dust by hand over the entire soil surface above each colony. In this case slightly more than 2 lbs. of the mixture was used per colony. Particular attention was given to placing the dust around each external opening to the nest and in those locations where the ants would be forced to walk through it while entering or departing from the colony.

Two weeks elapsed before the treated nests were examined again. Several heavy rains had occurred in the meantime. Little of the dust mixture was visible where it had been broadcast on the surface. In no case was there any indication that the dust had produced any toxic effects on the ants. Where the mixture had been blown into the nests, the ants had carefully removed all particles of leaf tissue bearing the dust mixture, depositing them outside the nest. Upon excavation of the nests it was found that numerous galleries and only a small percentage of the fungus gardens had been abandoned. Newly constructed galleries had been built. Activity within the colony seemed perfectly normal. There had apparently been less disturbance within those colonies where the dust mixture had been broadcast over the nest. If DDT had produced toxic effects on the ants and had killed any of them, evidence to that effect was lacking. All five colonies were heavily populated before and after the treatment. However, difficult as it was to ascertain any other noticeable effect on either the ants or the colony as a whole, their activity outside the nests seemed to have been reduced temporarily.

Dust mixtures like DDT-Pyrophyllite can not be applied satisfactorily to large subterranean ant colonies with available equipment. Since the dust tends to accumulate on the dampened walls of the galleries, at the unions of secondary canals and wherever sharp curves in the galleries are found, little or no dust reaches the vital fungus gardens. Furthermore, the fungus garden chambers are connected by very small canals which impede the entrance of dust particles. These details were exhibited in all the treated colonies.—3-12-45.

DDT to Control the Chinch Bug

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During the summer of 1944 DDT (2,2-bis (*p*-chlorophenyl)-1,1,1-trichloroethane) was tested near Lafayette, Ind., as a barrier against the nymphs of the chinch bug, *Blissus leucopterus* (Say), migrating into two fields of corn from adjacent wheatfields, and as a dust for the control of nymphs feeding on oats and corn.

In the barrier tests, dusts containing 5 or 10 per cent of DDT in pyrophyllite were sown on a strip about 3 inches wide, at the rate of about 1 pound to the rod, along the front and sides of 2-row plots of corn each containing about 18 plants. The treatments were triplicated in one field and quintuplicated in the other, in a single row of plots along the side of the field next to the wheat. The treated plots were separated from one another by similar plots of unprotected corn plants and from the rest of the field by a continuous line of dust containing

FIG. 1.—Plot of corn protected from migrating chinch bug nymphs by a line of DDT-pyrophyllite dust at front and ends, and by a line of 4,6-dinitro-o-cresol dust in rear. Lafayette, Ind., July 1944.

8 per cent of 4,6-dinitro-o-cresol. This dust protected the back of each plot and also the field in case the DDT mixtures failed to destroy the nymphs. In one series only one application was necessary. In the other the application had to be repeated because strong winds blew the mixtures away and produced clear spaces in the line. No rain fell during the 10-day migration period.

The 5 and 10 per cent DDT concentrations were equally effective in preventing damage to the corn. A majority of the nymphs died shortly after coming in contact with the material, but some of them crossed the line and climbed the plants; these too died in a few days. There was no visible injury to the plants except for a slight curling of the bottom leaves. The corn between and in front of the protected plots was completely destroyed by the nymphs (Fig. 1). Results indicate that a 5 per cent DDT-pyrophyllite dust is as effective a barrier as an 8 per cent dinitro-o-cresol dust, that a concentration of DDT higher than 5 per cent is not necessary, and that lower concentrations might be found efficient.

An experimental plot on the Purdue University Soils and Crops Farm, containing a number of strains of oats, was invaded by chinch bug nymphs from adjacent barley plots, and injury was evident. Little control was obtained when a number of rows were lightly hand dusted with 5 per cent of DDT in pyrophyllite. A 10-per cent DDT dust, in a considerably heavier application, by which the stems and the soil at the base of the plants were completely covered, produced complete control. No damage to plants occurred.

Popcorn and sweet corn test plots infested with chinch bugs were dusted once with 1 to 5 per cent of DDT in pyrophyllite. The mixtures were equally effective at all concentrations, with no damage to the plants. All the nymphs with which the dusts came in contact were killed. The few that escaped were those protected by tight leaf sheaths. It was observed that after about 2 weeks, during which time some rain fell, the treated plants again became moderately infested.

In the laboratory all nymphs exposed to dusts containing 1 to 5 per cent of DDT in pyrophyllite until thoroughly covered succumbed within 1 to 18 days, the majority dying within the first 7 days. All concentrations were about equally effective. The nymphs that survived for several days were nervous, excited, and did little feeding.—1-4-44.

DDT to Control the Carrot Rust Fly[1]

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The carrot rust fly, *Psila rosae* Fabr., is now fairly established in northern and northwestern Oregon. Control studies have been in progress for a two year period.

Randomized and replicated small plot field tests were carried on at Woodburn, Oregon during 1944. A three per cent DDT dust (Geigy) was applied to seedling carrots at the rate of 8 ounces to a 30 foot row. Carrots were approximately a half-inch high at the time of application and rust flies were active in the field. No later applications were made. The DDT treatment showed significant improvement over any other treatment and averaged 12 per cent of wormy carrots. This figure may be contrasted with 56 per cent of wormy carrots for the untreated check. Many of the wormy carrots in the treated plots were not greatly impaired by the rust fly larvae while most of the wormy carrots in the check plots were discarded as culls.

Later, randomized and replicated small plot tests were made using DDT dust (3 per cent Geigy) as a seed treatment. This material was applied at the rate of 2.5 pounds per 180 foot row. The results were very promising. The treated plots averaged 1.3 per cent wormy carrots as compared to the average of 20 per cent of wormy carrots in the untreated checks.

There was no evidence of plant injury from either the dust or seed treatment on carrots, although the rate of germination of the seed treated carrots was slightly retarded.—3-13-45.

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Use of DDT for Mosquito Control in the United States[1]

(A joint statement of policy by the U. S. Army and the U. S. Public Health Service)

SUCCESSFUL use of the new insecticide DDT to combat insect-borne disease among our troops overseas has brought sudden renown and notoriety to this potent war-developed insect killer. Dramatic reports of its large scale use to control epidemics, and especially the spraying of DDT from aircraft have fired public imagination and fostered the hasty conclusion that DDT is a complete solution to all of our insect-borne disease problems. However, it must be remembered that DDT distributed over the countryside not only wipes out malaria-carrying mosquitoes but also may kill other insects, many of which are beneficial. Much still must be learned about the effect of DDT on the balance of nature important to agriculture and wild life before general outdoor application of DDT can be safely employed in this country. It may be necessary to ignore these considerations in war areas where the health of our fighting men is at stake, but in the United States such considerations cannot be neglected.

Extensive investigations are now being carried out by authorized agencies to determine the usefulness and possible hazards in the large scale dissemination of DDT. Until more information has been obtained from such investigations and until it has been evaluated by all interested parties, plans to employ DDT indiscriminately for outdoor area control of insect disease vectors in this country are not to be encouraged.

Since the beginning of mobilization the Army has carried on an extensive anti-mosquito campaign inside of military reservations and the U. S. Public Health Service has maintained a cooperative program for the control of malaria in adjacent extra-military areas. This joint effort has successfully prevented malaria from becoming a problem to troops in this country. To meet the hazard of possible spread of malaria by troops returning from overseas, the Army's program in military areas has been intensified and the program of the U. S. Public Health Service has been extended to include certain additional selected areas in the south where risk of transmission is greatest. Representatives of the Army and the U. S. Public Health Service have given full consideration to ways in which this mosquito control program might be strengthened by employing DDT. The following joint policy has been agreed upon pending acquisition of further knowledge concerning the large scale outdoor application of DDT.

1. DDT will be used for residual spray application to houses and other buildings for the purpose of killing adult mosquitoes before they have opportunity to transmit malaria. The long-lasting killing effect of DDT as a residual spray provides a highly effective means to prevent the spread of the malarial parasite. This method of use is safe and economical, and moreover, is welcomed by the householder because it provides freedom from insect annoyance.

2. The use of DDT as a mosquito larvicide will be limited to experimental investigations and to situations where DDT has definite advantage over other larvicides in saving materials and manpower, and where it presents no hazard to fish and other wild life.

3. Distribution of DDT from aircraft for large scale area control of mosquitoes in military and adjacent areas in the United States will be limited to projects conducted with due regard to the possible effects of DDT on beneficial insects and all forms of plant and animal life and in accordance with safeguards established by the Surgeons General of the Army and the U. S. Public Health Service.

[1] Inasmuch as this issue of the JOURNAL is devoted wholly to reports of work with DDT it seems fitting that the statement printed above be given prominence. L.M.P.

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